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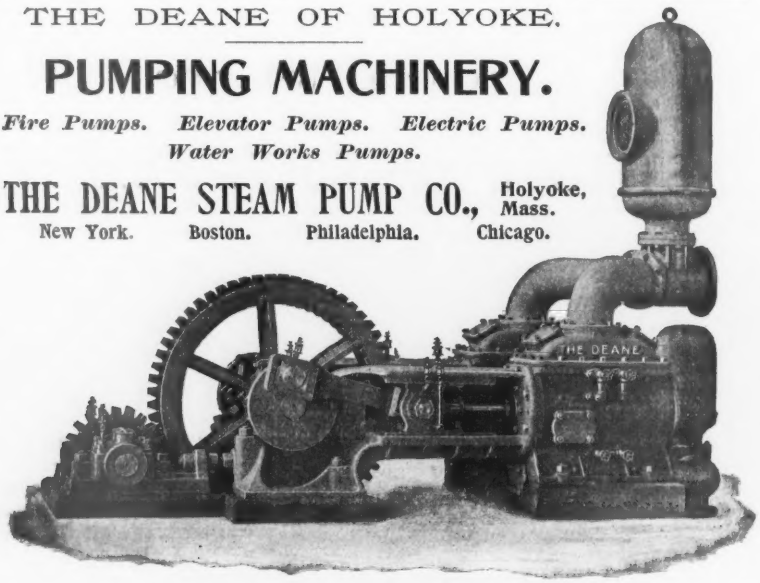

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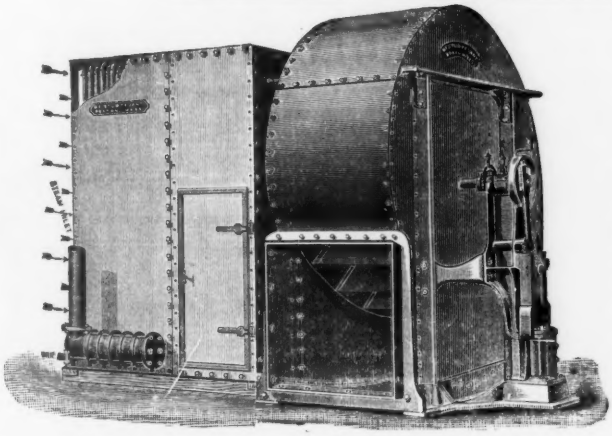

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THE TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS.

EDITED BY

ROBERT P. BIGELOW, Ph. D.

THE TECHNOLOGY QUARTERLY is an illustrated magazine published by the MASSACHUSETTS INSTITUTE OF TECHNOLOGY. It is devoted to original articles upon various subjects in **Architecture, Civil Engineering, Mechanical Engineering, Electrical Engineering, Physics, Chemistry, Biology, Bacteriology, Mining** and **Metallurgy,** or, in general, the **Sciences** and their applications to the **Useful Arts.** Attention is called to two especially notable features of the QUARTERLY, viz.: *The Results of Tests made in the Engineering Laboratories* and *The Review of American Chemical Research.*

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PROCEEDINGS OF THE SOCIETY OF ARTS.

VOL. XII. MARCH, 1899. No. 1

PROCEEDINGS OF THE SOCIETY OF ARTS.

THIRTY-SEVENTH YEAR, 1898-99.

BOSTON, October 13, 1898.

THE 514th regular meeting of the SOCIETY OF ARTS was held at the Institute on this day at 8 P.M., with Professor W. T. Sedgwick in the chair, thirty persons present.

The record of the previous meeting was read and approved. The following papers were presented by title:

"Producing Illuminating Gas and Coke in By-Product Ovens," by H. O. Hofman.

"A Modification of Bischof's Method for Determining the Fusibility of Clays, as Applied to Non-Refractory Clays, and the Resistance of Fire Clays to Fluxes," by H. O. Hofman.

"Does the Size of Particles Have any Influence in Determining the Resistance of Fire Clays to Heat and to Fluxes?" by H. O. Hofman and B. Stoughton.

The Chairman then introduced Mr. Simeon C. Keith, Jr., of Boston, who read a paper on "Bacteria in Milk, including their Rôle in Butter and Cheese Making."

Mr. Keith gave a general description of bacteria, and especially those in milk, with their functions in the ripening of cream. He

described briefly the various methods of separating milk and cream, especially that of the centrifugal machine, explained the use of special cultures of bacteria in butter and cheese making, and compared the value of various kinds. Then followed a description of some dairies visited, with a statement of what might properly be expected from them.

A discussion followed, after which the Chairman thanked Mr. Keith for his interesting paper, and the Society then adjourned.

BOSTON, October 27, 1898.

The 515th regular meeting of the SOCIETY OF ARTS was held at the Institute on this day at 8 P.M., with Professor Peabody in the chair, twenty-five persons present. The record of the previous meeting was read and approved.

Mr. P. B. Wesson, of Lowell, and Mr. William L. Draper, of Boston, were elected Associate Members of the Society.

The Chairman then introduced Mr. Henry G. Kittredge, of Boston, who read a paper on "Wool; with Practical Features that Enter into the Forming of a Wool Tariff. A Description of the Processes of Manufacture," with stereopticon illustrations.

He explained the essential differences between angora, alpaca, and merino sheep, showing that the classification is based on the differences in species. The operations of shearing, washing, scouring, sorting, etc., were described, and the careful methods in vogue in Australia dwelt upon to some extent. The different grades of wool from the same fleece were illustrated, and the processes of manufacture described.

A discussion followed, after which a vote of thanks was given to Mr. Kittredge for his excellent paper, and the meeting then adjourned.

BOSTON, November 10, 1898.

The 516th regular meeting of the SOCIETY OF ARTS was held at the Institute on this day at 8 P.M., with President Crafts in the chair, eighty-eight persons present. The record of the previous meeting was read and approved.

The Chairman then introduced Mr. Frederic P. Stearns, Chief Engineer of the Metropolitan Water Board, who read a paper on the "Metropolitan Water Supply," illustrated by stereopticon views.

Mr. Stearns gave a luminous account of the work done by the board, and of the many difficulties which had vanished as the work progressed. The problem consisted of two phases: to collect good water and send it to the Sudbury system of reservoirs, and to distribute it to the cities and towns within the ten-mile limit.

The completion of the tunnel and aqueduct to Basin 5 left the dam at Clinton, and the stripping and cleaning of the Wachusett Reservoir, as simple though immense operations to be performed. The distribution problem is now partially solved by the construction of two 48-inch pipe lines from Chestnut Hill to Spot Pond in Malden. The completion of the high service reservoir in the Fells will finish the work for the northern district.

The natural topography at both Clinton and Malden is so fortunate that the board is saved many millions of dollars by taking advantage of it. As a result, the water will cost very much less per million gallons than that of the large Croton Reservoir of New York, and even much less than the water from the economically constructed reservoir of the Sudbury and Cochituate systems. A discussion followed, after which the Chairman thanked Mr. Stearns for his very interesting paper, and the meeting then adjourned.

BOSTON, December 8, 1898.

The 517th regular meeting of the SOCIETY OF ARTS was held at the Institute on this day at 8 P.M., with President Crafts in the chair, seventy-two persons present. The record of the previous meeting was read and approved.

Mr. Henry B. Dates, of Potsdam, New York, Professor of Electrical Engineering in the Clarkson School of Technology, and Dr. Frederic S. Hollis, of Newton Highlands, were elected Associate Members of the Society.

The Chairman then introduced Professor W. O. Crosby, of the Massachusetts Institute of Technology, who read a paper, illustrated by lantern views, on the "Geology of the Wachusett Reservoir."

He gave a description of the geological features of the Nashua Valley, and of the strata encountered in the tunnel. The leading feature in its geological history was the influence of the glacial epoch. Large deposits of sand were laid down, and the action of the ice in the glacial lake, at that time occupying the larger portion of the valley, was to form the series of kettle holes, some of which contain small and even large ponds, which are so prominent a feature of the valley. The cut made for the discharge of the water in Sandy Pond led to the discovery of buried kettle holes where the ice boulder had been buried under one or more sand layers before melting.

The feature of leading importance to the engineer was the great difference between the two sides or walls of the valley. The southern side is steep and angular, with hard rocks, diorites, and quartzites predominating, while the northern and western sides are shelving and sloping, and composed of soft and cleaving rocks, such as mica schist. A great many borings were made on the sites of the great dam, and of the earthen dikes, and the facts thus ascertained were of the greatest importance in planning for the construction of the works.

A discussion followed, after which the meeting adjourned.

BOSTON, December 22, 1898.

The 518th regular meeting of the SOCIETY OF ARTS was held at the Institute on this day at 8 P.M., with President Crafts in the chair, three hundred persons present.

The Society met with invited guests for the purpose of opening the Pierce Building to the interested public. Addresses were made by the President, Professor Homer, Professor Woodbridge, Professor Puffer, Professor Sedgwick, and Professor Lanza, explaining the design and construction of the building, and the various problems met.

The guests and members then visited the various departments in the building, also the engineering laboratories. Refreshments were served in the lunch room.

ARTHUR T. HOPKINS, *Secretary.*

REPEATED STRESSES.

By JEROME SONDERICKER.

Read January 12, 1899.

Repeated stresses are of common occurrence in engineering structures. The moving parts of machines are, as a rule, subjected to such stresses. A piston rod, for example, changes from tension to compression at each stroke, and this is accompanied by bending if the alignment is imperfect. Connecting rods and parallel rods are subjected to alternate tension and conpression, accompanied by bending back and forth. The stress in the fibers of a shaft rotated under a transverse load, changes from tension to compression and back at each revolution. Propeller shafts, crank shafts, and car axles are under similar treatment. Ordinary wagon axles are repeatedly bent in one direction due to the roughness of the ground. A rail is bent each time a car wheel passes over it. A band saw is bent and unbent as it passes on and off the pulley. The parts of a bridge are subjected to repeated stresses as the loads pass on and off. There are varying stresses due to the action of wind and wave, also to changes of temperature, etc.

Breakages in such cases as I have mentioned are, more or less frequently the result of these repeated stresses. It is evident that a thorough acquaintance with the conditions which lead to such breakages is of great importance to the engineer.

When wrought iron or structural steel is tested in an ordinary testing machine, by pulling apart in tension, by bending, crushing, etc., the piece is broken by a load gradually applied once. The material being ductile, is considerably distorted before fracture takes place, the circumstances leading to fracture being those which accompany the flow of a plastic mass. The circumstances accompanying fracture under repeated stresses are entirely different, so that the strength of a piece under such stresses cannot be learned from the results of an ordinary test. Although Wöhler began his repeated stress tests nearly forty years ago, much still remains unknown respecting the effect of such stresses. Moreover, the information already gained seems not to have reached the notice of many engineers, if we may

judge from statements appearing frequently in the engineering periodicals.

The tests to be presented in this paper were made on rotating shafts, subjected to a transverse load, the stress, therefore, varied during each revolution between tension and compression of equal intensity. The specimens tested included wrought iron and structural steel, the steel varying in carbon from .08 or less, to .50 per cent., and in tensile strength from about 45,000 pounds to about 100,000 pounds per square inch. The speed of rotation varied from about 350 to 500 revolutions per minute. With the exception of a few cold rolled pieces, the metal was tested in the condition in which it came from the mills. The testing machine has been described in a previous paper. (See *Technology Quarterly*, April, 1892.)

Fig. 1.

The sets recorded in the tables need explanation. The measurements are taken between two arms clamped to the shaft 10 inches apart (Figure 3.) As the shaft revolves each fiber is alternately stretched and compressed. If the shaft be stopped with a given fiber on the compression side and then unloaded, the shaft, because of the set, will retain a slight curvature, with the fiber in question on the concave side, as $x\,y$ (Figure 1). If, on the other hand, the shaft were stopped 180° from its former position and then unloaded, the same fiber would be on the convex side, as $x'\,y'$. The difference in length of $x'\,y'$ and $x\,y$ is the set recorded. It is somewhat less than would be the case if the piece were subjected to direct tension and compression stresses, because the interior fibers, being under less stress, tend to straighten the shaft when it is unloaded.

Our present object is to give a general discussion of the results obtained up to date. These include, in addition to the writer's tests, three theses by graduates of the Massachusetts Institute of Technology, namely: Stephen Bowen, class of 1892, E. B. Carney, 1893, and M. E. Taylor, 1898.

The investigations were conducted along two lines. 1. The determination of the elastic changes resulting from the repeated stresses, and the influence of such changes in causing fracture. 2. The influence of form, flaws, and local conditions generally in causing fracture. These will be discussed in turn.

I. Elastic Changes Produced by Repeated Bending Stresses.

The planning of the tests was based on the consideration that structural or other changes in the metal would probably be accompanied by elastic changes. A careful study of the elastic changes occurring was, therefore, made. The details of the method followed are explained in my first paper. It is sufficient here to say that accurate measurements of the elastic strains and set were made at intervals during each test. Some of the bars broke without any such changes occurring. In the majority of cases, however, such changes did occur.

1. *Characteristic Curves of Set.* — Figure 2 indicates the general character of the changes which occurred in the set, the abscissae being the number of revolutions, and ordinates the amount of the set. *a* is the characteristic curve for wrought iron, and also occurred in one kind of soft steel. No change is produced until the elastic limit is reached, and then the change consists in a decrease of set, comparatively rapid at first but finally ceasing, unless fracture intervenes. In some of the wrought iron specimens this gradual decrease was preceded by an initial increase of set. *b* is the characteristic curve for all the steels tested, with the single exception mentioned. It is the reverse of the preceding, beginning commonly below the elastic limit and consisting of an increase of set, rapid at first but finally ceasing. Under heavy loads the increase of set is very rapid and ceases comparatively quickly. Accompanying the change of set there is a change in the elastic strain in the same direction but much smaller in amount. From the fact that these changes finally cease, we conclude that if of sufficiently small magnitude, they do not necessarily result in fracture. From the opposite character of the curves, it would seem that they indicate different kinds of internal change, or are the resultant of at least two kinds of change, one or the other predominating.

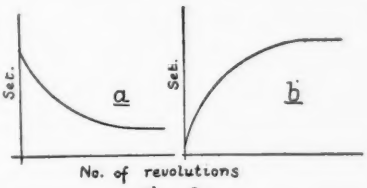


Fig. 2

2. *Stress at which Elastic Change was First Observed, Compared with Elastic Limit and Tensile Strength of the Material.* — Table I contains the results bearing on this point. The 3d column gives the

stress at which elastic change was first observed. In several cases it is evident from the magnitude of the set that changes would have been detected under smaller stresses had the observations been taken. The numbers in the 4th and 5th columns indicate the relative magni-

TABLE I.

Mark.	Material.	Stress at which change was first observed. (Lbs. per sq. in.)	Set.		Revolutions in which change occurred.	Original.		Per cent. of tensile strength.
			Original. (Inches.)	Final. (Inches.)		Elastic limit. (Lbs. per sq. in.)	Tensile strength. (Lbs. per sq. in.)	
D	Wrought iron.	30,000	<.01200	.00165	42,300	15,700	43,080	...
40	Wrought iron.	24,000	.00020	.00016	1,500,000	24,000	50,700	47.
1	Wrought iron.	26,000	.00018 .00026	.00018	2,214,000	25,900	51,390	50.
2	Wrought iron.	32,000	.00069 .00136	.00090	486,000	25,900	51,390	...
3	Wrought iron.	24,000	.00027 .00037	.00012	6,593,000	23,400	50,510	47.
4	Wrought iron.	28,000	.00021 .00042	.00032	2,506,000	23,400	50,510	...
33	Steel.	32,000	.00192	.00740	85,900	24,800	47,400	...
34	Steel.	32,000	.00202	.00832	103,500	24,800	47,400	...
21	Steel.	32,000	.00029	.00012	4,395,000	30,400	62,590	51.
54	Steel.	45,000	.00089	.00310	163,000	42,000	63,130	...
50	Steel.	30,000	.00036	.00100	339,000	23,200	73,760	41.
25	Steel.	40,000	.00016	.00028	5,031,000	38,300	78,010	51.
26	Steel.	40,000	.00017	.00025	20,838,000	38,300	78,010	...
18	Steel.	36,000	.00022	.00052	6,463,000	50,000	81,010	...
19	Steel.	36,000	.00008	.00069	7,252,000	50,000	81,010	...
20	Steel.	34,000	.00007	.00028	21,221,000	50,000	81,010	42.
53	Steel.	50,000	.00012	.00249	24,000	58,000	96,580	...
58	Steel.	45,000	.00003	.00020	50,100	58,000	96,580	47.
29	Steel.	40,000	.00007	.00046	5,257,000	54,000	104,480	38.
55	Steel.	55,000	.00018	.00060	276,900	50,000	104,830	33.
57	Steel.	60,000	.00208	.00768	14,300	50,000	104,830	...

tude of the set when the stress was first applied, *i. e.*, after a few revolutions, and after the number of revolutions given in column 6. The 7th and 8th columns give the elastic limit and tensile strength obtained from the usual tension test. In the wrought iron bars there was an initial increase of set as indicated in the 4th column. A perusal of

TABLE II.

Mark.	Material.	Stress.	Revolutions.	Maximum observed stress.	Remarks.
D	Wrought iron.	30,000	86,400	<.01200	Broke at one end, at shoulder, and at other end where arm was attached.
40	Wrought iron.	24,000	1,500,000	.....	
		26,000	2,427,000	.....	Broke.
1	Wrought iron.	26,000	2,285,000	.00026	Broke near center.
2	Wrought iron.	32,000	486,000	.00136	Broke at mark burned by electric current.
3	Wrought iron.	24,000	6,593,000	.00037	
		24,000	4,059,000	.00011	After resting unloaded 9 days.
		25,000	8,962,000	.00016	
		26,000	3,932,000	.00022	
		27,000	8,155,000	.00037	
		28,000	589,000	.00038	Broke at shoulder.
4	Wrought iron.	28,000	2,506,000	.00042	Broke at center.
33	Steel.	32,000	89,750	.00771	Broke outside of arm near bearing. Color, blue-black.
34	Steel.	32,000	116,600	.00832	Broke outside of arm near bearing. Color, blue-black.
21	Steel.	32,000	4,395,000	.00029	
		34,000	5,339,000	.00032	
		36,000	4,627,000	.00041	
		36,000	1,428,000	.00008	After resting unloaded 18 days.
		38,000	3,769,000	.00023	
		40,000	4,523,000	.00054	
		42,000	505,000	.00072	Broke near shoulder.
54	Steel.	45,000	163,000	.00312	Broke at shoulder.
50	Steel.	30,000	339,000	.00100	
		35,000	16,400	.00282	Not broken.
25	Steel.	40,000	5,031,000	.00028	
		42,000	2,483,000	.00046	Broke at shoulder.
26	Steel.	40,000	20,838,000	.00037	
		42,000	3,311,000	.00044	Not broken.
18	Steel.	36,000	6,982,000	.00052	Broke where arm was attached.
19	Steel.	36,000	7,686,000	.00069	Broke at shoulder.
20	Steel.	34,000	21,221,000	.00028	
		36,000	13,577,000	.00067	
		38,000	2,263,000	.00113	
		38,000	9,237,000	.00116	After resting 6 months, unloaded.
		40,000	932,000	.00177	Broke at shoulder.
53	Steel.	50,000	146,500	.00249	Broke at shoulder.
58	Steel.	45,000	50,100	.00020	
		50,000	156,300	.00289	Broke near middle.
29	Steel.	40,000	5,257,000	.00046	
		42,000	7,125,000	.00067	
		44,000	4,626,000	.00100	
		46,000	6,760,000	.00145	
		48,000	4,965,000	.00196	
		50,000	170,000	.00197	
		50,000	1,080	.00203	After resting unloaded 24 days. Not broken.
55	Steel.	35,000	276,900	.00060	
		40,000	237,900	.00274	
		50,000	22,530	.00615	Broke near shoulder. Color, dark straw.
57	Steel.	60,000	14,900	.00768	Broke near shoulder. Color, dark blue.

this table will show that in case of the wrought iron and one kind of soft steel (No. 21), the effect of the repeated stress was to decrease the set, and that this change apparently first occurred after the elastic limit was passed. (Compare Nos. 40, 1, 3.) In all other cases the set increased, this change apparently beginning below the elastic limit (Compare Nos. 18, 19, 20, 53, 58, 29, 55). That this change should begin below the elastic limit in the second instance and not in the first, would follow from the nature of the change. The last column shows that these changes of set may be expected to begin at stresses varying from $\frac{1}{3}$ to $\frac{1}{2}$ of the tensile strength.

3. *Relation between Elastic Change and Fracture under Repeated Stress.* — Table II gives the number of revolutions under the stresses indicated and the corresponding maximum set observed. From the nature of the case it is impossible to say precisely what connection exists between the amount of set and resistance to fracture. Even with a set of .001″, Nos. 20 and 29 sustained many millions of revolutions. With a set of .002″ and over, the pieces as a rule broke comparatively soon. About all that can be said is that the set does not

TABLE III.

Mark.	Material.	Set.		Maximum after rest.	Time of rest.
		Before rest.	After rest.		
2	Wrought iron.	.00108	.00070	.00092	17 hours.
3	Wrought iron.	.00021	.00017	.00017	5 days.
21	Steel.	.00019	.00008	.00008	5½ months.
54	Steel.	.00142	.00095	.00312	2 days.
50	Steel.	.00089	.00084	.00091	15 hours.
50	Steel.	.00282	.00269	.....	22 hours.
26	Steel.	.00037*	.00015	.00025	11 days.
20	Steel.	.00024*	.00023	.00027	2 days.
20	Steel.	.00113	.00073	.00111	5½ months.
53	Steel.	.00249	.00210	.00412	6 days.
29	Steel.	.00111*	.00119	.00145	1 month.
29	Steel.	.00198*	.00203	.....	24 days.
51	Steel.	.00342	.00322	.00422	2 days.
55	Steel.	.00056	.00052	.00060	15 hours.
55	Steel.	.00275	.00234	.00272	2 days.

* Readings not taken *immediately* before stopping.

appear to have a notable influence in causing fracture until it reaches .001″ or .002″ in a length of 10″.

4. *Effect of Rest on the Set Produced by Repeated Stress.* — Frequently the bars rested over night, and in several cases they were laid aside for some time and then tested again. Some of the more important results are given in Table III. It will be seen that the effect of rest is to decrease the amount of set. In most cases, however, the set lost is soon regained, when the bar is again subjected to the repeated stresses. This is especially noticeable in the case of the harder steels.

5. *Temperature Effects.* — It was noticed throughout the tests, that when running under any considerable set, the shaft was perceptibly warmer in the middle than at the bearings, the temperature increasing with the set. There was no accurate way of measuring this temperature. In four cases, however, the heat was sufficient to color the shafts. No. 55, running under a stress of 50,000 pounds, and a set of about .006″ reached a full straw heat (about 200° C.) before breaking. No. 57 under 60,000 pounds stress, and Nos. 33 and 34 under 32,000 pounds stress reached a blue heat (about 300° C.) before breaking, the set in each case being about .008″ (see Table II). Nos. 33 and 34 were a very soft steel, and Nos. 55 and 57 hard steels. The temperature will, of course, depend upon the relative rate at which the heat is generated and dissipated. If a shorter length of shaft had been under the maximum stress, or if the speed had been less, the temperature reached would have been less, and conversely. In all four cases, the break occurred near the bearings, *i. e.*, where the shaft was coolest. This is in harmony with the fact that steel at a blue heat has a higher tensile strength than at a lower temperature. These results would seem to indicate that these high temperatures are not detrimental to the strength of steel under repeated stresses.

6. *Effect of Repeated Stress and Subsequent Rest upon the Tensile Strength.* — Some of the bars broken by repeated stress, were, after varying periods of rest, tested in tension. The tensile strength and ductility obtained in a few cases are given in Table IV, and compared with the original tensile strength and ductility of the metal. It will be seen that the tensile strength is increased to a marked extent in the soft metals, and slightly in the harder steels. The ductility of all is slightly diminished. These results do not indicate the full extent

TABLE IV.

Mark.	Material.	Original.		Per cent. contraction.	Repeated Stress.		Final.		Per cent. contraction.	Time of rest.
		Elastic limit.	Tensile strength.		Maximum stress.	Maximum set.	Elastic limit.	Tensile strength.		
D	Wrought iron.	15,700	43,080	71.5	30,000	<.01200	.....	51,180	66.7	Some weeks.
33	Steel.	24,800	47,400	67.7	32,000	.00771	33,000	58,500	63.9	2 days.
29	Steel.	54,000	104,480	40.3	50,000	.00203	59,600	106,200	37.3	6 years.
55	Steel.	50,000	104,830	33.0	50,000	.00615	.....	110,100	28.4	7½ months.

of the change as the interior has been under less stress than the surface of the bars. The bars of Table IV had all been subjected to heavy stresses accompanied by considerable set. When the bars are run under stresses causing no elastic changes, as far as is known, no change of elastic properties results from subsequent rest.

7. *Explanation of These Phenomena.* — We wish to know the nature of the internal changes which are indicated by the elastic changes described. While the information at hand is not sufficient to determine this definitely, it suggests possible explanations which will be presented briefly. The reduction in set in the case of wrought iron is similar to that produced by any cold working of the metal, such as stretching, hammering, etc. It seems probable that the effect of the continuous kneading to which the soft iron is subjected in the Repeated Bending Machine, is to stiffen it somewhat. The increase of set observed in steel, both below and above its elastic limit, is probably due to causes which must be sought for in connection with the micro-structure of the metal.

According to Professor Howe, Mr. Sauveur, and others, ordinary unhardened steel may be described as granular in structure, and is made up of two constituents called ferrite and pearlyte. The ferrite is nearly pure iron containing no carbon. Pearlyte is made up of ferrite and a carbide of iron, which latter is so hard as not to be scratched by a needle. The proportion of this carbide increases with the percentage of carbon. Steel is thus non-homogenous, and its different constituents doubtless possess different elastic properties.

Set apparently must indicate either plastic distortion of the par-

ticles or lost motion between them, or both, as change of distance between two nuts on a screw may be due to the screw stretching, or to backlash. The increase of set below as well as above the elastic limit which occurs in steel, may be due to the stress being unequally distributed through the mass. To illustrate, — imagine a bundle of wires, some ductile, others hard and brittle, loaded in tension so that all must stretch equally. When the elastic limit of the ductile wires is passed, they will no longer support their portion of the load, some of it being transferred to the more unyielding wires. The hard wires might be able to withstand one application of this unduly heavy stress, but might fail if such stress were repeated a sufficient number of times. The effect of such failure would be to stretch the ductile wires further.

Similarly, in a non-homogeneous material such as steel, the different portions of its structure are probably unequally stressed. When the elastic limit of the soft portion is reached, the more unyielding parts must be stressed excessively. If under repeated applications of this stress they yield, by fracturing or otherwise, the soft portions will be further distorted until equilibrium is again established, *i. e.*, the set would increase. At the same time the working of the soft iron would stiffen it. Under these combined influences, the increase of set might finally cease, and possibly be succeeded by a decrease. Some such action as that described would account for the behavior of the steels under repeated stresses.

A systematic study of the chemical composition and micro-structure of the steel, made in connection with such tests as have been described, could hardly fail to be of value to both the engineer and metallurgist. In none of these tests was there any noticeable change of structure, crystallization, or anything of the sort. No. 55 had been subjected to repeated stresses of such magnitude as to raise the temperature of the bar to a straw heat, after which it rested $7\frac{1}{2}$ months. If any change of structure were to occur, it would be looked for under such severe conditions. Yet when pulled in tension afterwards, the fracture was not different in appearance from the original. The same is true for No. 33, which had been raised to a blue-black heat by the repeated stresses.

It may be well here to say that, unless one is familiar with the appearance of fractures, erroneous conclusions are liable to be drawn from them. In the same metal, the appearance of the fracture varies

greatly with the way in which it is produced. When ductile iron or steel is pulled apart in tension, the metal is drawn down, the particles are very much disturbed and distorted, the fracture resulting from the flow of the metal. If the same bar be nicked or cracked, and then broken suddenly, there is no opportunity for this flow of metal to occur. The conditions of fracture are similar to those of a brittle material, and the appearance is quite different from the preceding. In a shearing fracture the sliding action produces an appearance sometimes described as silky. Under repeated stresses the piece gradually cracks through, with no more alteration of section than in a cracked piece of crockery.

II. Influence of Form, Flaws, and Local Conditions Generally, in Causing Fracture.

In Figure 3, *B B* are the supports, and *C C* the boxes at which the loads are applied, the portion of the shaft between these latter being under uniform bending moment. The measuring arms were attached by means of split rings, *A A*. These rings indented the shaft slightly. In some cases the shafts were of uniform diameter; in others the middle portion was reduced a trifle in diameter, as shown. As the whole length of shaft between the inner boxes, or between the shoulders when the shaft was turned with shoulders, was subjected to the same stress, the fracture would occur at the weakest section in this length. The influence of local conditions in determining the point at which fracture began could thus be observed.

The fractures in this respect are grouped as follows: 8 broke without any local cause being apparent; 9 broke at or near one of the shoulders; 3 where one of the measuring arms was attached, the ring causing an indentation of about .001″; 2 at slight flaws in the surface of the bar, and 1 at a place where the bar was slightly burnt by the electric current. In two instances the fracture occurred where the stress was less than the maximum. One bar broke at a slight flaw, the stress being 4 per cent. less than the maximum, and the other at a dent .005″ deep, where the stress was $13\frac{1}{2}$ per cent. less than the maximum.

Mr. Carney, in his thesis, made a further investigation into local conditions affecting fracture, as follows:

In steel bar No. 24 a groove about .003″ deep was cut by a diamond pointed tool. The shaft was also indented by three set screws, namely,

by a cup-shaped one and a round-ended one each to a depth of $\frac{1}{64}''$, and by a pointed one to a depth of $\frac{1}{32}''$. Under these conditions the bar withstood 6,000,000 revolutions under a stress of 20,000 pounds, but broke after 2,300,000 revolutions under a stress of 25,000 pounds, the break occurring at the groove. This bar was from the same steel as No. 21, which had sustained 6,000,000 revolutions under 40,000 pounds stress, and broke after 500,000 revolutions under 42,000 pounds stress. The groove had apparently reduced the strength about 40 per cent.

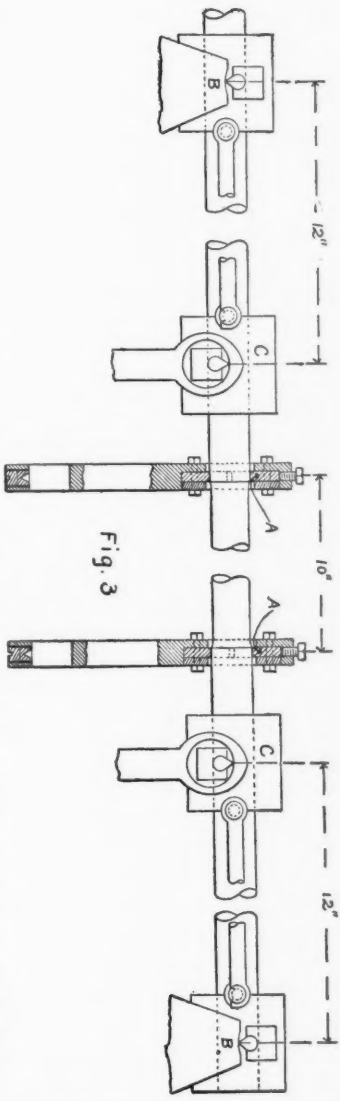


Fig. 3

Steel shaft No. 29 had previously withstood 5,000,000 revolutions under 48,000 pounds stress, and did not break after 200,000 revolutions under 50,000 pounds stress. One inch length of this shaft was then reduced in diameter from 1″ to .9″ with square shoulders. In this condition it broke after 276,000 revolutions under 30,000 pounds stress. The fracture took place at one of the square shoulders, the crack forming a ring concentric with the shaft. The shoulder also reduced the strength about 40 per cent. The stresses are estimated on the net section; *i. e.*, the strength in this case was 40 per cent. less than what it would have been if the whole shaft had been turned down to the diameter of the smallest section. Another steel shaft, No. 22, from the same steel as Nos. 21 and 24, was treated the same as No. 29, and after withstanding 8,000,000 revolutions under 20,000 pounds stress,

broke after 689,000 revolutions under 25,000 pounds stress. The reduction of strength here is also 40 per cent. No. 30, from the same steel as No. 29, was treated like Nos. 29 and 22, and after withstanding 6,000,000 revolutions under 25,000 pounds stress, broke after 629,000 revolutions under 30,000 pounds, the fracture occurring at a square shoulder as before. Nos. 22 and 24 were a soft steel of .08 per cent. carbon, and 62,600 pounds tensile strength. Nos. 29 and 30 were a hard steel of .485 per cent. carbon, and 104,500 pounds tensile strength. The strength of both under these repeated stresses was reduced about 40 per cent. by such grooving and shoulders as described.

Flange Couplings.

The subject of Mr. Bowen's thesis was, "Tests of Flange Couplings under Repeated Stress." The dimensions of the couplings tested

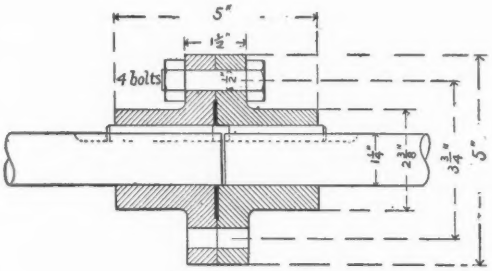


Fig. 4.

are given in Figure 4. They were proportioned in all their details according to the rules given in Machine Design, and were made with due care. They were tested in the repeated stress machine with a view to determining the efficiency of the joint and the weakest point in it under such stresses. Wrought iron and steel shafts $1\frac{1}{4}$ inches in diameter were tried. The wrought iron had a tensile strength of 50,700 pounds, with 15 per cent. elongation in 10″, and the steel a tensile strength of 62,200 pounds, with 20 per cent. elongation in 10″. The solid shafting was first tested. The wrought iron solid shaft broke after 2,500,000 revolutions under 26,000 pounds stress, and the steel after 1,000,000 revolutions under 38,000 pounds stress, it having previously withstood 10,000,000 revolutions under 36,000 pounds stress.

The couplings were then tested by joining two pieces of shaft together, and testing as for a solid shaft. Three couplings were tested, two with steel shafts, one with wrought iron. In all cases the shaft fractured, the parts of the coupling showing no signs of weakness. In all cases the break occurred at or near the edge of the boss, the crack starting apparently at the edge of the keyway. The position of the crack is shown in Figure 5.

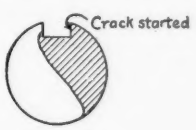


Fig. 5.

The stresses at which fracture occurred are as follows: With steel shafts, one broke after 2,740,000 revolutions under a stress of 20,000 pounds. The other withstood 10,500,000 revolutions under a stress of 16,000 pounds, and then broke after 5,000,000 revolutions under a stress of 18,000 pounds. With wrought iron shafts, fracture occurred after 2,400,000 revolutions under a stress of 20,000 pounds. It would appear, therefore, that the wrought iron and steel under these conditions had about the same strength. If we take 18,000 pounds for the breaking stress, this is about 35 per cent. of the tensile strength of the iron, and less than 30 per cent. of that of the steel. Comparing with the strength of the solid shaft under repeated stress, the strength of the steel shafting was reduced fully 50 per cent. by the coupling, and that of the wrought iron shaft about 23 per cent. In other words, the efficiency of the couplings under repeated bending stresses was, for the steel shafting 50 per cent., and for the wrought iron shafting 77 per cent.

The local conditions which determined the position of the fracture were evidently the keyway, and possibly the pressure of the coupling boss. The conditions in these tests are similar to the case of a pulley or fly-wheel keyed to a shaft.

From the cases mentioned it appears that small imperfections in the metal have a noticeable effect in causing fracture under repeated stress. The importance of having the metal free from flaws and bruises is evident. The bad effects of square shoulders in shafting, axles, etc., are quite generally known to engineers, but the extent to which the strength is reduced by such conditions may not be fully appreciated. In such a connection as a flange coupling, the problem, so far as strength is concerned, is to connect the two shafts with as little reduction in strength, compared with the strength of the solid shaft, as possible. We also wish to know the amount of reduction of

strength in any given case. When the piece is to be subjected to repeated stresses, tests under similar conditions are evidently necessary in order to determine the strength of the joint. A more important case is that of riveted joints. They are often subjected to repeated stresses, yet their resistance to such stresses has never been investigated. The information we have to depend upon is that obtained by pulling the joints apart in an ordinary testing machine. It is improbable that the proportions which will give the greatest efficiency under such tests would be most efficient under repeated stresses. The same criticism applies to the determination of the relative value of punched and drilled holes.

The usefulness of the ordinary tests when properly interpreted is unquestioned, but there are many points in design which cannot be determined by such means. The tests discussed cover, of necessity, a very limited field. The influence of chemical composition, heat treatment, etc., has not been touched upon. Also, there are repeated direct tension, compression, torsion, and other stresses to be considered. The field is practically limitless. For this reason, also, importance was attached to the study of the elastic changes produced; for a thorough knowledge of the nature of the accompanying internal changes would simplify further investigations, and make the facts already obtained more available.

DISCUSSION OF PROFESSOR SONDERICKER'S PAPER ON REPEATED STRESSES.

By JAMES E. HOWARD, Watertown Arsenal.

Read January 12, 1899.

Professor Sondericker has presented a valuable paper on a specially interesting field of inquiry, and I have been gratified to observe the close harmony existing among the results presented by him, and those which have been developed at the Watertown Arsenal.

In the Watertown tests two principal objects have been in view, namely, to ascertain the total number of repetitions of stresses necessary to cause rupture, and to observe through what phases the physical properties of the metal pass prior to the limit of ultimate endurance. The Watertown tests have included cast iron, wrought iron, hot and cold rolled metal, and steels ranging in carbon from .10 per cent. to 1.10 per cent., also nickel steels. The fiber stresses have ranged from 10,000 pounds per square inch on the cast iron bars up to 60,000 pounds per square inch on the higher tensile strength steel bars.

The specimens were in the form of rotating shafts subjected to transverse loads. The speed of rotation was from 400 per minute up to 2,200 per minute in different experiments. Observations were made on the deflection of the shafts and on the sets developed. It was early observed that intervals of rest were followed by temporary reduction in the magnitude of the sets. The Report of Tests of Metals for 1888 takes up this feature. Deflections were measured under different fiber stresses, both when the shafts were at rest, and when rotating under high speeds.

Quoting from the above-mentioned report, "the deflections tend to diminish under high speeds of rotation when the loads exceed the elastic limit of the metal, and tend to cause permanent sets; but, on the other hand, when the elastic limit is not passed, the deflections are the same within the range of speeds yet experimented upon." This quotation marks the distinction between deflections when elastic

strains only are involved and cases of permanent sets. Efforts were inaugurated at this time to ascertain the effect of repeated alternate stresses on the tensile properties of the metal, and it appeared that such treatment tended to raise the tensile strength of the metal before rupture ensued.

Subsequently, in 1892, annular forms of tensile specimens were taken out of the transverse shafts. The results with this form of specimen, wherein only the metal remote from the neutral axis was examined, confirmed the earlier observations. The changes in tensile properties are most pronounced in the softer grades of steel, a fact quite consistent with the behavior of common tensile specimens, if we consider the stress per square inch on the section at rupture in comparison with the strength referred to the original area, or if we bear in mind the comparative effects of cold working on mild steel and on harder metal. It is not every test that furnishes an example of higher tensile strength in metal which has been subjected to repeated alternate stresses. Frequently incipient cracks have developed before the tensile test-piece is taken out, and then an apparent loss in tenacity is shown over the original strength. One favorable example will be referred to, taken from the results given in the Report of 1893. A cold-rolled steel shaft was annealed at 1,800° F., then tested for endurance under a computed fiber stress of 40,000 pounds per square inch, rupture occurring at 102,000 rotations.

The subsequent test by tension of this metal showed a tensile strength of 73,240 pounds per square inch for the part which had been exposed to the above-mentioned fiber stress, and 61,920 pounds per square inch for that part of the shaft which had not been exposed to those repeated stresses. The effect of higher temperatures in increasing the endurance of the metal was shown by a number of steel bars which ran at temperatures in the vicinity of 400° F., or above, the highest being 472° F.

The following table is taken from the Report of 1893, showing the relative endurance of hot and cold bars. From the wide range in carbon in these bars, and the fact that each of the hot bars largely exceeded in endurance its companion cold bar, we infer that these tests established the fact that the endurance at from about 400° to 472° F. is greater than at atmospheric temperatures.

It will be observed in this connection, that the tensile strength of steel is greater in the above zone of higher temperatures than at ordi-

Carbon.	Total Number of Rotations.	
Per cent.	Hot Bars.	Cold Bars.
0.15	85,200	4,350
.17	32,300	3,950
.34	127,700	11,600
.55	111,800	11,950
.73	218,500	34,900
.82	148,200	42,000
1.09	99,200	23,000

nary temperatures, while it is probably true on the other hand that the elastic limit is somewhat lower. It is certain that the modulus of elasticity diminishes with increase of temperature. These and other results lead to the inference that tensile strength is a function of the endurance of metals to repeated stresses, and logically we must extend the inference and conclude that rupture will not take place until the stress reaches the ultimate tensile strength of the material. Now since we rupture shafts under repeated stresses which do not appear to reach even the tensile elastic limit, it is necessary to offer some explanation of this seeming discrepancy. It is believed that a gradual introduction of internal strains takes place, and their cumulative effect, together with the external applied stress, is adequate to strain individual parts of the metal to their ultimate limit and cause rupture; and that rupture is not caused until such strain or corresponding stress is reached.

The greater mobility of steel at a blue heat, as shown by the lower modulus of elasticity, we might readily suppose to be a favorable condition to promote endurance, certainly when combined with a higher tensile strength. The effect of cold rolling, cold swaging, and wire drawing, is to increase tensile strength. Why should not repeated stresses have a similar effect on tensile strength? The former kinds of treatment introduce intense internal strains, why not the latter?

Concerning the limit of indefinite endurance to repeated stresses we know but very little. In most experiments rupture occurs after a few thousand repetitions, so high have been the applied stresses.

Examples are not uncommon in railway practice, of axles having made 200,000,000 rotations.

In order to establish a practical limit of endurance, indefinite endurance, if we choose to call it so, our experimental stresses will need be somewhat lowered or new grades of metal found.

Many of the arsenal tests have been made with a maximum fiber stress of 40,000 pounds per square inch. This load was found adequate to cause rupture, with less than 5,000,000 repetitions for all shafts experimented with up to a recent date, although in one instance a specially treated bar was tested which showed a tensile elastic limit of 117,000 pounds per square inch, and tensile strength of 151,000 pounds per square inch.

An exception to the above statement has now appeared in a bar of high manganese steel furnished by the Bethlehem Iron Company which has endured over 80,000,000 rotations under 40,000 pounds per square inch fiber stress, and the shaft is not yet broken. This bar has the following chemical analysis:

Carbon, .39%. Manganese, 1.82%. Silicon, .64%.

It has been subjected to special treatment by quenching from a high temperature and annealing. Associated with the question of indefinite endurance, is the problem of how to raise that limit in steels of different grades. Various combinations of physical properties may be imparted to steels, but they are not of a permanent character when examined by means of repeated alternate stresses.

A new apparatus has been made at Watertown for tests by repeated stresses, in which six specimens are under test at a time. An innovation in this machine is found in the provision made for applying longitudinal stresses in combination with transverse stresses on rotating shafts. The relation of the two stresses can be so adjusted that the shaft shall alternate between a maximum and minimum tension, a maximum and minimum compression, or any given values of tension and compression.

THE PLANNING AND BUILDING OF THE SOUTHERN STATION, BOSTON.

By GEORGE B. FRANCIS.

Read January 26, 1899.

Upon the railroad routes within fifty miles of Boston about 50,000,000 passengers are carried to and from Boston each year, nearly equally divided between the North and South stations.

The close approximate population within the fifty-mile, or say suburban limit, is 2,392,000. Within the same limit around Philadelphia it is 2,289,000; around Chicago, 1,188,000; around St. Louis, 874,000; and around New York. 4,754,000; New York only exceeding Boston. These figures show the reason for large terminal facilities in Boston, and the existence of the South Terminal station.

The engineering force appointed by the terminal company to carry out the construction of the South Terminal station reported for duty on the first day of July, 1896. Accurate surveys were immediately commenced, covering the area to be occupied by the station, and some of the surrounding territory also, for the purpose of carefully defining the boundary limits of the various private ownerships, and for making a complete topographical record.

As the expenditure for land was liable to be nearly double the expenditure for construction, this work was done with great care, and all the base lines were made to conform with those of the various railroad, city, and state departments who had established them through this territory for various purposes. A constant checking with these parties, eliminating disputes where they existed, finally resulted in a survey accepted by all as satisfactory. Detail plans of each piece of property were made for permanent record in plat book form, preserving all measurements and data obtained which could be of use as reference in any case. Location maps and descriptions of land taken were also made for file in the public records, as required by the terminal act.

While this work was going on, the chief engineers of the interested roads and the manager of the terminal visited various railroad terminal stations in Europe to make critical examination, and to acquaint themselves with the many details and ways of carrying on such stations abroad.

The architects also were preparing several exterior designs for a head-house, various schemes for the layout of the public rooms for the station, and endeavoring to determine a proper arrangement for the general offices to be used by the different roads.

A fund of information was also being accumulated for reference regarding American stations, and particularly those of Boston.

Borings were also made to obtain the best information possible about the strata within reach beneath the station.

It was early decided that the new station must be so built that the new motive powers, electricity and compressed air, one or both, could be used therein; that a large increase in suburban trains, due to smaller train units and more frequent service, could be had; and that every effort possible should be made to remove the handling of baggage from the passenger platforms.

About the first of October, 1896, the first general ground plan, embodying the ideas accumulated, both as regards the arrangement of the rooms in the head-house and the arrangement of the tracks and platforms, was made.

The first plans made contemplated only a single floor for train service; but after arranging as well as possible for the various controlling features, making numerous studies for the exclusion of baggage trucks from the passenger platforms, and developing several ways of expeditiously handling electric cars, considering both high platforms on a level with the floor of such cars and low platforms as an alternative, it was found that such unusual features tended to use up space, and that instead of thirty or more tracks, which it was hoped could be had, the number was reduced to twenty-eight. This was discouraging, as the old stations contained an aggregate of twenty-five tracks, and the increase of three only did not promise that opportunity for future growth that it was reasonable to expect.

There being no reasonable hope that a greater width of land could be secured, attention was directed to the possibility of divorcing the suburban, or short distance service, from the long distance service and placing the former at a different level, thus doubling the room for

tracks on certain areas. The first sketch of this sort diverted the proposed suburban tracks from the main approach tracks about a half-mile from the station, and by a gradually rising grade brought several tracks on either side of the train shed to a level about 24 feet above the main floor. These were to be stub tracks, like those on the main floor.

This arrangement did not do away with the necessary switch system for making up trains outside of the station for each floor level; and upon its development it was seen that if the elevated stub tracks could be connected in the form of loops, the train movements would be very much lessened and the number of switches at the entrance largely reduced. The extreme width of the station made the loop connection possible, and a plan was drawn accordingly. This was the first loop-track study. There was some doubt, however, as to the advisability of having upper platforms about 28 feet above the main floor (which would be the case if high platforms were used), both on account of the appearance of the structure, the difficulty of handling baggage, the nuisance from the smoke and steam of the locomotives below, as well as the advisability of avoiding stairs. The approaching grades were also steeper than was desirable.

The possibility of a suburban loop track service upon a floor beneath the main floor was next considered. As the main floor of the station was designed at that time to be only about 6 feet above the highest tides, it required to be raised to the highest level possible without the use of stairs at the entrances from the streets, which was prohibited. The main floor was raised 4 feet, and inclines were introduced at the entrances.

Even this placed the lower tracks, which were finally designed to be 17 feet below the main floor tracks, 7 feet below very high tides. This immediately introduced the study of water-proofing this great area to shut out the water. Due consideration showed it feasible to do this without prohibitory cost. Placing the loop tracks 17 feet below the main floor and using high platforms for this kind of service made easier approach grades, stairways of 13 feet rise instead of 28, as was the case with elevated suburban tracks, and simplified the handling of baggage, improved the appearance of the main floor, and did away with the smoke nuisance.

The main station building was also drawn, set back from Summer Street, so that inclined approaches could be had to or from the first

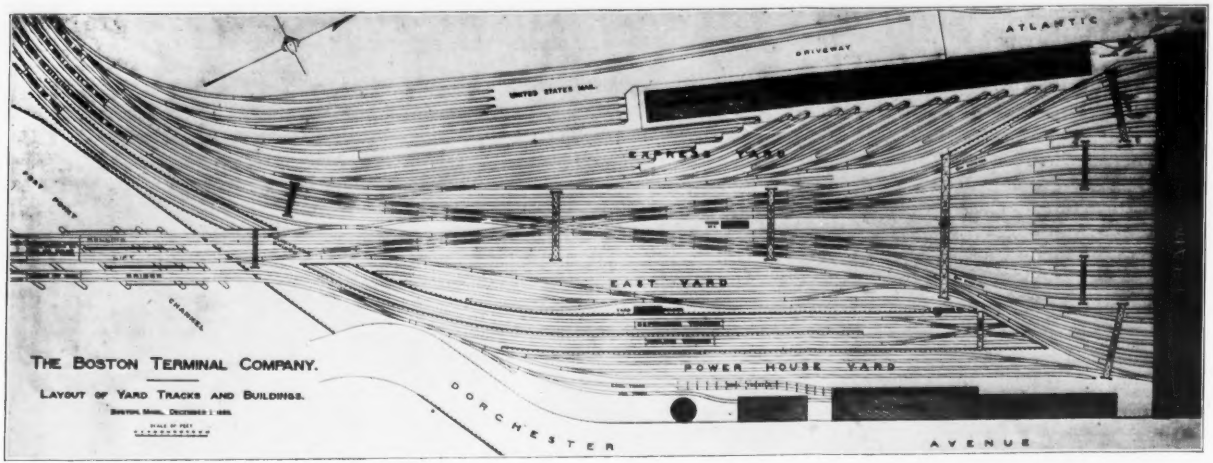
loop track, as well as to the main floor. Stairways were drawn from the main floor to the lower floor, so that all persons taking loop trains at the station could reach them by going down stairs only.

Before the loop plan was adopted it was drawn in various ways and positions, sometimes with two loops, sometimes with four, sometimes with curved corners, and some straight tracks; also tracks curved throughout. Studies were made of methods of handling the passengers and building the cars.

The one great feature which made the loop system attractive was the making of this great terminal a through station for one kind of service and a terminal station for the other. Suburban trains do not carry mails, express matter, or baggage in any quantity. They carry people only, and should be run frequently and got out of the way rapidly. The through station idea makes it possible to handle as many trains at the terminal as it is possible to run over a main line. Trains leave their passengers and move on without switching. If the coming motive power is electricity, through a third rail, it does not conflict with the immense switching system which must be maintained at so large a terminal.

As this station must eventually provide for suburban trains from four main lines — the Boston & Providence, Old Colony, New England, and Boston & Albany Railroads — such trains must leave the station at shorter intervals than trains could be run on either main line alone. This is provided for by arranging, with a minimum amount of switches, two loop tracks to be used alternately, each capable of holding several trains, one track to be filled while the other is being cleared. More loops meant more switches — the very thing to be avoided. By this means trains can remain in the suburban station much longer than the actual time interval between trains. These loops could have been arranged to operate with even less switches than designed, but it would have obliged all trains on some routes to use one loop track exclusively, whereas it was desirable to make the forward loop available for all routes to its full capacity.

After adjusting the loops, the arrangement for baggage handling was so drawn that there should be nine baggage and express trucking platforms the entire length of the train shed, independent of the passenger platforms, and an underground passage was designed to allow the baggage trucks to cross beneath the tracks. This method, which it is believed will very much reduce the baggage nuisance gener-



LAY-OUT OF YARD TRACKS AND BUILDINGS.

ally experienced, requires seventeen baggage and express lifts, eight in the train house, four in the baggage rooms, and five in the express buildings.

Not the least of the station problems most vital to the successful operation of the station is the track arrangement necessary just outside of the station for the safe and expeditious handling of the trains. Alternative plans devised by various citizens for this situation omit this feature of the subject as one not requiring attention, or as a feature that may be treated as entirely subordinate to the station. The reverse, however, is the case, as the station is subordinate to the track arrangement.

There will be about 700 trains transferred to the new station from the old ones. An actual count at the old stations indicates about 4,000 movements in 18 hours each day through these switches. There will probably be more than this in a few years. It is believed that the arrangement adopted is simple and ample. By it the station may be operated as a unit, incoming trains on one side and outgoing trains on the other side, or in four sections, one for each of the four main lines.

Buildings have been provided for handling the mails and express, for supplying power to heat and light the station, also to make ice and Pintsch gas for the trains and for other purposes.

Having outlined the general features to be provided for operation, it became a question as to whether it was wise to incur the expense necessary to build the double floor station. Estimates showed that the cost of this additional floor, which, it was admitted, would nearly double the capacity of the station and provide a great reserve capacity whenever needed, would add only about 6 per cent. to its cost.

This additional cost was within reason, and the terminal trustees adopted this arrangement. On December 22, 1896, they submitted the plans to the mayor for his approval, which was obtained, and on January 4, 1897, the railroad commissioners, after several public hearings, placed their indorsement upon the plans. Two days later, on January 6, 1897, invitations were sent out for steel to be used in the train shed and track floors, and a contract was signed February 1, 1897.

That as much advantage as possible be taken of the winter weather, a preliminary contract was made for excavation and the driving of 2,000 piles on January 11, 1897. The sale and removal of

private buildings was begun, the New England railroad buildings having been removed during the fall of 1896.

Meantime architects and engineers were busily engaged in developing working drawings and specifications of foundations and superstructure for the main buildings and train shed, so that when spring opened the work could be vigorously prosecuted. Bids for this work were received, and on April 7, 1897, a contract was awarded for the larger portion of the work to a Massachusetts contractor, O. W. Norcross, the proprietor of a number of quarries, stone-working plants, and wood-working and other shops.

It was decided that pink granite from Stony Creek should be used for the buildings, which were to be partly of two stories and partly of five; that the train shed should consist of three spans and the midway of one span.

The ground underneath the building was originally overflowed by the ocean, and was later covered with docks, wharves, and buildings founded on cribs, walls, piles and rubbish, a large portion of which had to be removed. The entire structure necessarily stands on piles, of which there are about 26,000.

To exhibit the immensity of the undertaking, a diagram was prepared showing how twenty-four prominent buildings of Boston could be founded within the area covered by the main structure. A list of these buildings is as follows: Mechanics' building, City Hall, Public Library, Postoffice, Exchange building, Ames' building, Trinity Church, Old South Church, Old State House, Cadet armory, Masonic Temple, Hotel Touraine, Hotel Vendome, original portion of present State House, Faneuil Hall, Faneuil Hall market, Herald building, and the following minor buildings to fill the smaller spaces: Worthington building, Carter building, Waban building, Y. M. C. A. building, Hotel Copley, Hotel Austerfield, apartment house Le Brun.

At the time of starting the work public travel existed over streets to be abandoned, sewers were in use upon which it was necessary to expend upwards of $100,000 to readjust them to the new conditions, water pipes and hydrants were in service, telegraph, telephone, electric light, police, and fire alarm wires were in the way. Electric conduits and gas mains also encumbered the ground.

There were many leases of property not yet expired, even after extinguishment of owners' titles. All of the coal in the great coal pockets, some of which were in the act of loading up from vessels, as

PILE TEST.
SIXTY TONS OF PIG IRON RESTING ON THREE PILES WITH NO RESULTING SETTLEMENT. PILES SPRUCE, 27 FEET IN GROUND. PENETRATION, 3 TO 4 INCHES AT LAST BLOW OF 2000 LB HAMMER FALLING 16 FEET WITH HAMMER LINE ATTACHED, AND NOT EXCEEDING 10 INCHES AT ANY ONE BLOW FOR WHOLE DEPTH. DESIGNED LOADING 10 TONS PER PILE.
10
FEB. 5, 1897.

THE PILE TEST.

well as all the stock and machinery in the various buildings, had to be removed before the buildings could themselves be torn down. All of these obstacles and many more were gradually overcome, and the razing of the buildings proceeded as if by magic. On February 5, 1897, a loading test was made to demonstrate the carrying capacity of spruce piles in the underlying strata. This load was 60 tons of pig iron upon three spruce piles, driven 27 feet into the ground, with a penetration of 3 to 4 inches at last blow of 2,000 pound hammer falling 16 feet, with the hammer line attached, and not exceeding 10 inches at any one blow for whole depth; proposed final load, from completed structure, to be 50 per cent. of the test load, which latter gave no resulting settlement.

The coffer dam which it was necessary to construct, and without which it would have been impossible to have executed the work, merits a brief description.

As the borings show an underlying stratum of clay within reach of a single length of timber, it was evident that a continuous timber wall driven into this clay close enough to prevent the leakage in the joints would positively exclude the water. With this sort of a wall surrounding the work no trouble would result in execution. In some places this line of timber wall, consisting of 6-inch splined hard pine planks, in about 40 feet lengths, was doubled to give sufficient lateral strength to resist pressure from open water; at other places it was a single line.

Wherever this sheet piling was driven it was necessary to first entirely remove any stone or timber in the way. Any failure to do this was disastrous. There were some exasperating delays in the removal of the obstructions, obliging the use of several divers and a wrecking outfit, but eventually the entire terminal excavation was shut off from the salt water on three sides, and in some pockets on four sides, with this timber wall.

From the very start up to the present date there has been no flooding of the lower floor, the coffer dam having effectually done its work. The cost of this dam has been about $75,000. It is also of use in connection with the permanent shutting out of high tides, thus reducing excessive pressure on the water-proofing. By some it has been considered that the coffer dam presented the most difficult feature of the undertaking, and that without success in this particular it would be impossible to execute the work.

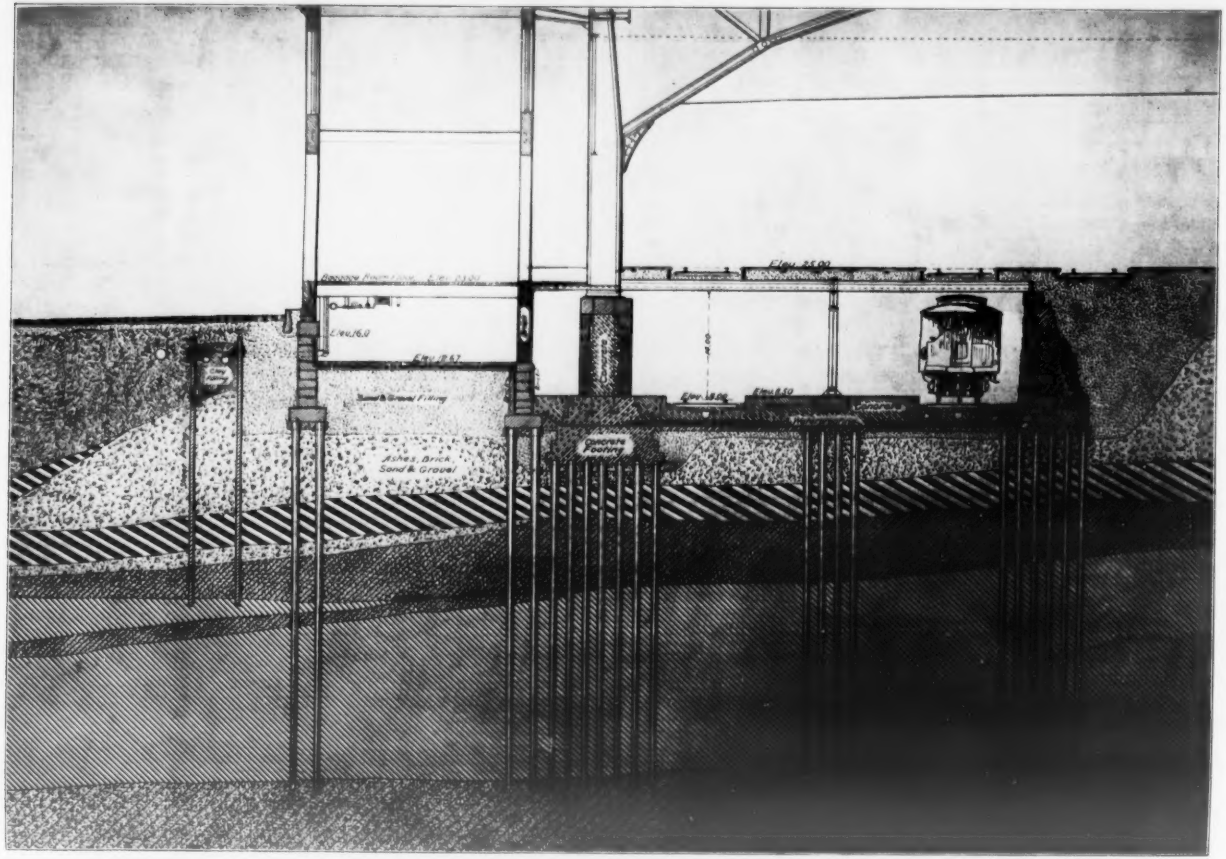
The permanent water-proofing sheet, which underlies the whole lower floor, consists of ten layers of tarred paper, swabbed together with hot coal tar pitch. The layers are carefully lapped, and all built in place. This continuous sheet of water-proofing, amounting to 56,000 square yards, or upwards of 10 acres, is laid, where horizontal, upon a concrete base, trowelled to a smooth surface. In some of the softer places boards were laid down under the concrete base, but usually this base, 6 inches thick, rests upon the ground. Where the water-proofing is on the vertical walls, it is backed up with 8 inches of brick work. In all cases the horizontal sheet lies between the pile heads and the granite masonry above.

Upon the water-proofing sheet where it is not weighted down with walls, there is placed a loading of a cheap grade of Portland cement concrete, sufficient to resist the upward pressure of the water, which is, on the horizontal layers, about 500 pounds per square foot, this pressure being dependent, of course, on the elevation of the sheet, with reference to the ground-water level. In some places the weight of the walls is far in excess of the water pressure; in others, where possible, the pressure is resisted by inverted concrete arches. The water has been more effectually shut out by this sheet than was ever expected.

A drain-pipe channel underlies each loop track for its entire length, and these discharge into the sump well near the power house, where both rain water and any leakage through the water-proofing finds its way, either through the automatic tide gates at low tide, or is pumped at other stages of the tide into the Fort Point channel by means of two submerged centrifugal pumps, operated by electric motors and automatic floats. These pumps are capable of raising 5,000 gallons a minute, or about 7,000,000 gallons per 24 hours.

The first steel was received in Boston, April 1, 1897. It continued to arrive, and a place at the southerly end of the train shed was cleared and graded to store it. Tracks were laid to this point, and the 900 carloads of steel were gradually deposited contiguous to the work. About 25,000 cubic yards of excavated material from beneath the head-house was carried away into the country at the start, but all other excavated material of the 275,000 cubic yards handled has been used in the filling required around the terminal.

During the months of April, May, and June, 1897, the city of Boston made a start at several points on the construction of the sea



CROSS SECTION OF EASTERN PART OF FOUNDATION AND SUBWAY, SHOWING STRATA PENETRATED BY THE PILING, COFFER-DAM, WATERPROOFING, ETC.

wall built by it along Dorchester Avenue. Grades were also fixed for all the streets surrounding the new station.

On June 28, 1897, a contract was made for the general mechanical and electrical equipment of the station, divided into the following heads: Interlocking plant and signals, boiler plant, engine plant, ice plant, lighting, arc and incandescent, heating, cold water and refrigeration, ventilation, hot water for cleaning, air for brake testing, elevators, steam heat for cars, protection for roof conductors, fire protection and pumping plant. Negotiations for this comprehensive contract had been under way for about six months, and the decisions reached were arrived at only after long and careful study.

The granite used in the work has been brought from the following quarries: Stony Creek, Connecticut; Milford, Massachusetts; Rockport, Cape Ann, Massachusetts; Pigeon Cove, Cape Ann, Massachusetts; Mt. Desert, Maine; Croacher's Island, Maine; Deer Isle, Maine; Northbridge, Massachusetts; Fitchburg, Massachusetts; Pascoag, Rhode Island; Milford, New Hampshire. In addition to this, large quantities of granite from Quincy, Massachusetts, found in the old work has been used again.

On October 16, 1897, the Terminal Company was enabled to take full possession of Federal Street, between Essex Street and Kneeland Street. Greater progress could have been made if the streets could have been obtained earlier, but many things stood in the way of this. On December 4, 1897, a contract was made for steel rails. On December 20, 1897, a contract was made for the covering of the entire train shed and connecting roofs, followed later by a supplementary contract for all the platforms. This roof work was started at the terminal March 18, 1898.

The train shed is lighted through asbestos covered wire glass, bedded in putty, fastened in with wooden strips in wooden sash, fastened with brass screws to wooden frames bolted to the train shed steel. All the glass is set vertically, and permanent foot walks have been provided, so that it will be possible to reach each pane of glass in the shed at any time with brushes and water to keep it reasonably clean.

The main roof is an asphalt and gravel roof, the gravel being the white Long Island beach gravel. The monitors are covered with copper. The roof is designed to carry with perfect safety a uniformly distributed load of 60 pounds per square foot, including its own

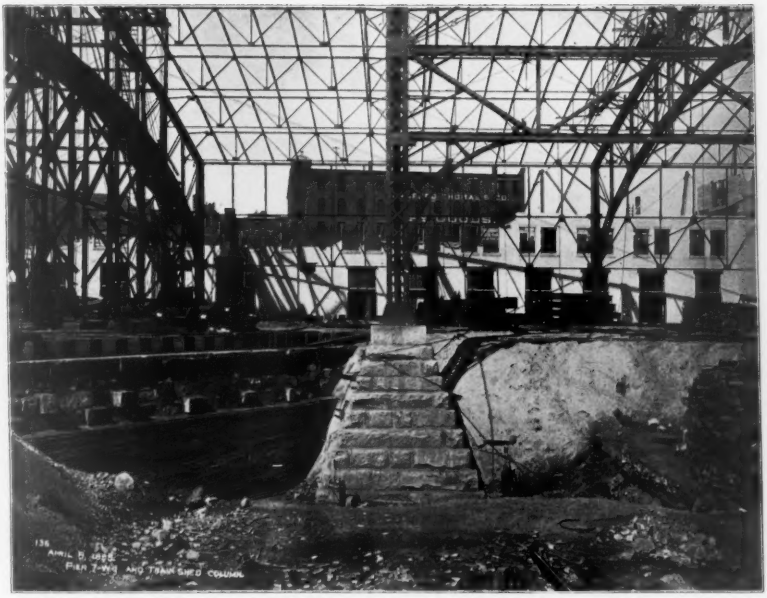
weight and several times this load before there is danger of rupture. The steel in the frame weighs about 23 pounds per square foot, and the coverings about 10 pounds more. It is not intended that it shall be necessary to shovel any snow from the main roof. All the down spouts are covered with jackets, and steam pipes have been run between the pipes and the jackets to keep them from freezing in the coldest weather.

On January 14, 1898, a contract was made for frogs and switches. These were delivered in July, August, and September, 1898. On February 5, 1898, a contract was made for the power-house buildings and subway work southerly of the main buildings, followed later by orders for the gas building and the express buildings. On March 3, 1898, a contract was made for the Pintsch gas plant.

From time to time orders were placed for ballast, ties (both ordinary and special), track fastenings, water connections and stand pipes, drains, and for many other minor details.

On March 7, 1898, the first pair of trusses for train sheds were erected ready to stand alone. On April 6, 1898, a contract was made for the sea wall along the Fort Point channel west of Federal Street. On June 9, 1898, Mt. Washington Avenue was closed to travel. On July 11, 1898, Federal Street, from the bridge to Kneeland Street, was abandoned by the city, and the extension of Dorchester Avenue was opened for travel. On November 4, 1898, the fires were lighted under the boilers, and on November 10, 1898, the first hot water was sent through the heating system.

The following brief statistics will give some idea of the multiplicity of details to be looked after in so large a project: Total area of terminal land, about 35 acres; total area covered by building, about 13 acres; maximum length of main station, 850 feet; maximum width of main station, 725 feet; average length of main station, 765 feet; average width of main station, 662 feet; area of main station, 506,430 square feet; area of awnings outside of buildings, 46,000 square feet; height of main station from sidewalk to top of eagle, 135 feet; length of express buildings, 712 feet; width of express buildings, 50 feet; length of power buildings, 569 feet; width of power buildings, 40 feet; total length of buildings on street front, 3,300 feet; length of train shed proper, 602 feet; width of train shed proper, 570 feet; height of train shed over all, 112 feet; train shed in three spans, middle span, 228 feet; two side spans, each 171 feet; trusses, canti-



PIER AND TRAIN SHED COLUMN; ROOF AND SIDE WALL OF SUBWAY, WITH BRICK BACKING, IS SEEN ON THE LEFT.

lever, and 60 feet center to center; area of midway, 60,000 square feet; area of connecting roofs, 17,500 square feet; length of waiting room, 225 feet; width of waiting room, 65 feet; height of waiting room, 28½ feet; total length of tracks, about 15 miles; total number of tracks entering the station, 32; of these, 28 are on the main floor, and 4 in the shape of two loop tracks on lower floor; length of tracks under roof, 4 miles; number of tracks through throat in yard, 8 for main floor, 4 for lower floor; total weight of rail, 2,500 tons; number of double slip switches, 37; number of switches, 252; number of frogs, 283; number of semaphore signals, 150; number of signal lamps, 200; number of levers in tower No. 1, 143; number of levers in tower No. 2, 11; number of signal bridges, 9; total number of trains to use new station when fully opened, 710 per day; number of 65-foot passenger cars that can be set against platforms on main floor of station, 344; of these, 252 will be under roof; number of 40-foot passenger cars that can be set against platforms on lower floor, loop station tracks, 60, all under roof; the seating capacity for the above cars is 28,104 people; capacity of express yard against platforms, 26 express cars and 12 mail cars; total capacity of mail and express yard, 116 cars; capacity of other yard tracks, 93 cars, making a grand total of 613 cars.

In connection with the station there are 235 arc lights, inclosed pattern; 6,000 incandescent lights, 1,200 of which are in the main waiting room; 25 electric elevators, 209 water closets, 138 urinals, 118 set bowls, 5 shower baths, 106 fire supply outlets, 14 water meters, 29 storage vaults, 43 toilet rooms, 215 office rooms, 1,000 window shades, 200,000 pounds sash weights, 120 connections for supplying Pintsch gas to cars, 36 ticket windows, 95 baggage-room doors, 69 express building doors, 10 steam boilers, 4 electric generators, 9 compressors, 45 electric motors, 20 heating and ventilating fans, 25 steam engines, and 1 traveling crane.

The material used to complete the work approximates: 43,000 spruce piles, 15,100,000 common brick, 487,000 medium brick, 846,000 enamelled brick, 74,000 cubic yards concrete, 32,000 cubic yards stone masonry, 30,000,000 pounds or 15,000 tons steel, equal to about 1,200 car loads; 200,000 cubic feet of cut stone for building, or 500 car loads; 75,000 barrels Portland cement, 20,000 barrels Rosendale cement, 8,000 barrels coal-tar pitch, 6,500 barrels prepared asphalt, 850,000 pounds tarred paper, 450,000 pounds sheet copper for

roof trimmings; 5,000,000 feet B. M. yellow pine timber, for various uses; 16,000 pounds solder, 10 acres of gravel roofing, 150,000 square feet wire glass, 40,000 pounds or 20 tons of putty to set the same.

There are 56,000 square yards water-proofing, and about 200 acres of painting, reduced to single coat. The clock dial in tower is 12 feet in diameter, and the granite eagle is about 8 feet high, 8 feet wide, and 8 tons weight.

THE MECHANICAL EQUIPMENT OF THE SOUTHERN STATION.

By HENRY J. CONANT.

Read January 26, 1899.

From the preceding paper by Mr. Francis on the new Southern Station, one may obtain an excellent idea of the magnitude of the undertaking, for the conception and successful execution of which he is so largely responsible. The scale on which this work has been carried on is apparent on every hand, but to some of you nothing may be any more suggestive of the scope of the work than the fact that the mechanical equipment for the operation of the station, exclusive of all track and structural work, involves an expenditure of nearly three-quarters of a million dollars.

This equipment is far more complete and comprehensive than is provided for any other railroad station in the world. It comprises an extensive interlocking system for switching and signaling; a large power plant; elevators and lifts for carrying passengers and baggage; the warming and ventilating of the various buildings; a plant for making ice for use in restaurants and cars; a refrigerating plant for cooling provision boxes and storage rooms in the head-house; a plant for filtering and cooling drinking water; service for car heating; appliances for charging air brakes prior to the departure of trains; a high pressure water service for fire protection; a pumping plant for freeing portions of premises which are below tide water, from storm water or from possible seepage through water-proofed structure; provisions for preventing the stoppage of roof conductors by freezing; furnishing supplies of steam and hot water in the head-house, etc.

The engineering work involved in extended researches into the needs and experiences of the more important Terminals in this country and abroad, and in the preparation of detailed designs and specifications for a comprehensive equipment adapted to the requirements of the new Southern Station, was placed in the hands of Westinghouse, Church, Kerr & Company's engineers, representing in this case the

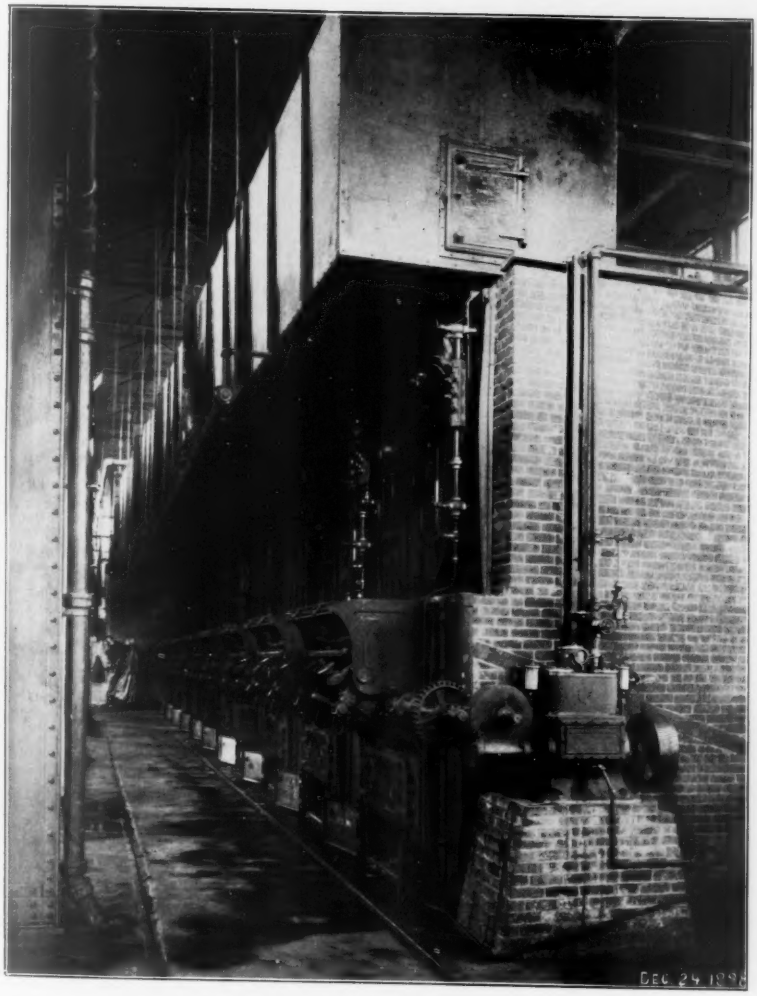
various Westinghouse interests. This was done at a sufficiently early stage of the undertaking to make it possible to remove obstacles of the kind usually encountered in work of this character, and to a considerable degree create conditions favorable to the best results, and much of the success which has been obtained may be attributed to the commendable foresight which led those in control of the enterprise to cause the mechanical engineering work to be treated in this comprehensive way. Although the provisions for the service at the new station are very extensive and unusually diverse owing to its size and particularly to the unique character of some of its more prominent features, the various portions of the equipment have been so successfully harmonized and made to relate one to the other so intimately, that a very considerable saving of apparatus and gain in simplicity and efficiency have resulted.

Power Plant.

The general arrangement of the power plant was largely determined by important considerations of track and yard facilities, leading to what some one has very aptly termed a "tandem" lay-out. The principal apparatus is contained in a building erected especially for the purpose, and occupying a space 460 feet long and 40 feet wide on the easterly side of the yard.

This plant furnishes power, light, heat, and refrigeration wherever required throughout the premises, and is the initial source of all the varied mechanical service that the station requires. Its design is based primarily on the principle of subdivision of power, the apparatus and size of units being chosen with special regard to the widely varying loads to be carried during different hours of the day and seasons of the year.

So far as possible, precautions have been taken to guard against accidental interruption of the service, and substantial relay has been provided throughout, either in the form of complete spare units or through a choice of units which permits of the loss of use of one without impairment of service. The steam piping is in duplicate in all its essential portions, but the arrangement is in such form as to avoid the complexity usually accompanying this feature of design, and at the same time allowing isolation and repair of any part without interruption.



View of Boilers and Stokers.

Boiler Room.

The boilers are of the well known horizontal return tubular type, 72″ in diameter and 18′ long. They are made from an extra quality of steel specially rolled for this plant to meet rigid specifications and tests, and are designed for carrying a working steam pressure of 150 pounds per square inch.

The furnaces are provided with an equipment of Roney mechanical stokers, and are adapted to burning widely different qualities of fuel, including "front ends" from locomotives, and either high or low grade coals, with the greatest possible economy and without smoke.

The waste gases are passed through a pair of improved circulating economizers, with dampers and by-pass so arranged that they may be operated singly, in parallel, or in series with each other, as the conditions of service may allow, thereby permitting the greatest possible saving to be made at all times.

Draft is furnished by a pair of large, slow-running fans, either of which is of sufficient capacity for the entire plant. The products of combustion, cooled by the economizers to a point at which natural draft could not be employed (except by the use of a chimney so large that its cost would be prohibitive), are discharged at a point a few feet only above the roof of the boiler house through a short and inconspicuous stack.

Provisions have been made for a substantial increase in boiler capacity whenever required, and consideration has also been had to the future installation of coal handling machinery so far as expedient to do so.

Engine Room.

Owing to the fact that electric current is used for many purposes to a varying extent, the load conditions are complicated, and much consideration was necessarily given to the choice of units for the most economical and reliable performance of the work. An opportunity to use exhaust steam in varying amounts at different hours of the day and seasons of the year also had a substantial bearing on the character of the units employed. For the purpose of studying their conditions, elaborate load charts were prepared for average days for each month in the year, each service having its separate curve.

To best meet the conditions so presented, four 18–30 x 16 Westinghouse compound engines, aggregating 1,500 horse power, were

used, each directly connected to a 225 k. w. Westinghouse multipolar engine type generator, capable of simultaneously generating current in any proportion at two potentials; one of 220 volts for power, and one of 110 volts for arc and incandescent lighting.

So far as the demand for exhaust steam requires, these engines are operated non-condensing, but any or all may be run under vacuum as occasion requires, the arrangement of exhaust piping being such that the exhaust from any engine may be readily carried into either the vacuum or the atmospheric side of the system while running.

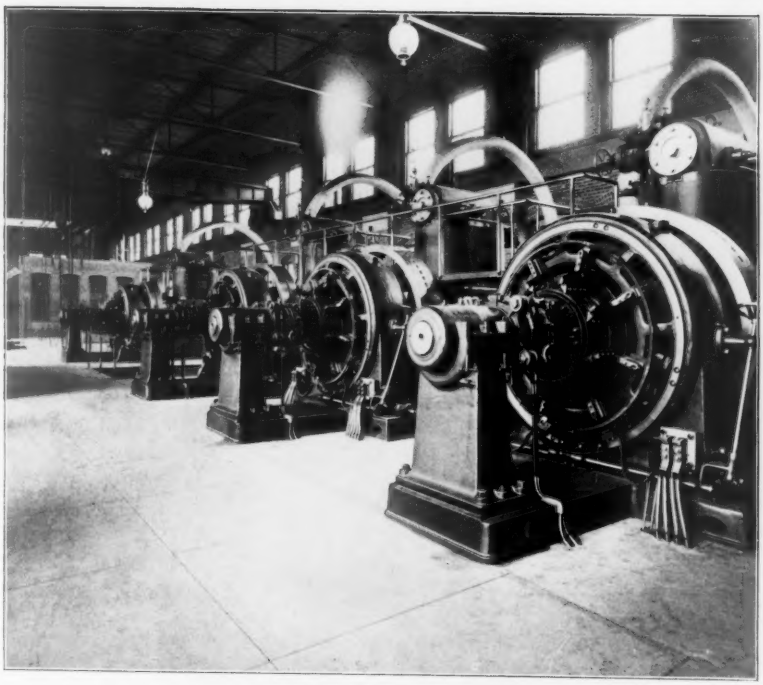
The design of the switchboard permits the separation of power and lighting service on a double set of bus bars whenever desired, and of carrying at will such pressure on any set of feeders as may be required to maintain a constant voltage at the principal distributing centers which have been established throughout the premises at a considerable distance from the power house. Outside of the features involved in the problem of "distribution," there is little in the electric wiring system that is of much more than ordinary interest.

All power circuits are run on a 220 volt two-wire system; 220 volt feeders are also carried to each of the distributiug points for the arc and incandescent lamps. Neutral balance wires are run from each of these distributing points and combined in a trunk neutral connecting through balance coils at power house with the generators, and providing a path to the armature circuits for any unbalanced load there may be in the 110 volt tap circuits.

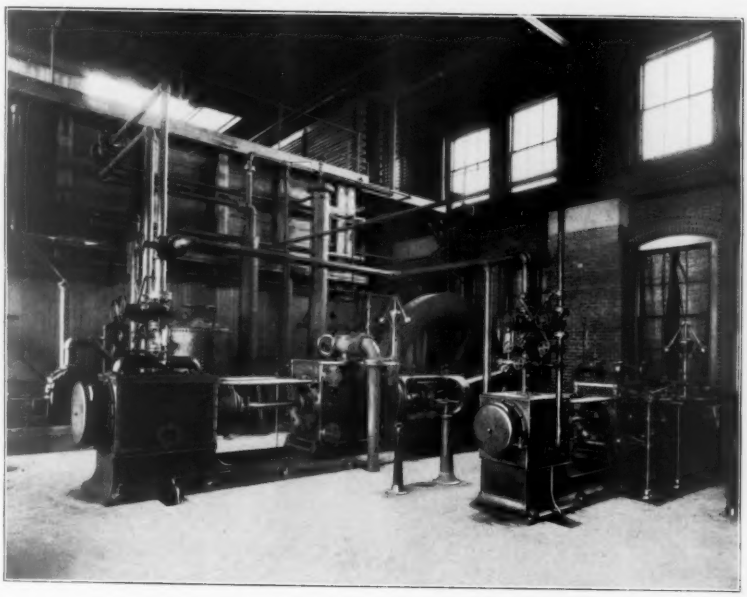
All principal distributing centers are provided with annunciator systems and pressure wires connecting with suitable instruments on the main switchboard at the power house, and pilot lamps at the distributing boards serve to show when the board is alive after a call for current is made. The installation contains a total of considerably over 6,000 incandescent and about 250 arc lamps.

Interlocking.

The switching and signaling system includes a very complete installation of Westinghouse electro-pneumatic interlocking apparatus for handling all the trains of the railroads using the station to and from the main train shed, and for the frequent trains which are to use the tracks in the suburban loop. The switches and signals are both operated by compressed air furnished from the power house, and the operating mechanism is controlled electrically from inter-



Engine and Dynamo Room.



Compressor Room, Ice Plant.

locking machines in the towers. Two interlocking machines are required for this work, and these are located in two interlocking towers built especially for their reception, and for the use of the men who are to operate them. Operating models of the tracks upon which each movement of the switches and signals is duplicated in miniature are provided at each machine, so that operators will always have before them the exact condition of the tracks under their control.

The signals are located in some cases on ground level, but are largely placed on nine signal bridges extending over the tracks and varying in span from about 50 feet to 120 feet. The signaling apparatus constitutes a complicated system somewhat similar to that in use at the Northern Station, but is more extensive and embodies a number of important improvements.

The principal objects accomplished by this interlocking system are to concentrate the operation of all switches at one point; to control movement of trains over them by use of fixed signals, also operated from a central point, interlocking the levers operating the switches and signals one with another, so that until all switches in a given route are properly set, the signal governing train movements over it cannot be "cleared," and conversely to prevent the movement of a switch while a signal governing a train movement over it is at "clear." This is accomplished through extremely ingenious combinations of mechanical and electrical devices which could not well be explained at length without models or recourse to elaborate details.

Car Heating and Air Service.

An extensive system of steam and compressed air piping has been distributed through the yards and train shed, and connected with the stub-tracks, for warming the cars while standing on the tracks in cold weather when the locomotive is detached, and to furnish a suitable supply of compressed air for the air brakes prior to the departure of the trains. This is an important feature in all terminal work, and in this instance is unusually complete.

Disposal of Water.

The disposal of water from the large extent of water-proofed structure involved somewhat unusual considerations, due to the fact that a large portion of the basements and all of the suburban loops are below tide water. A large sump well has therefore been built

near the power house in which electrically driven centrifugal pumps have been installed to pump away any possible seepage, storm water, and melting snows, which owing to the grades of the suburban track will necessarily be carried to the lower levels. The electrical pumping apparatus is controlled automatically by the level of the water in the sump, and a large reserve pump is provided to handle unusual quantities of water. Electric alarms are also provided to notify the power house attendants in order that they may start the large pump whenever the water might reach a predetermined danger level.

Heating and Ventilating.

A positive hot water circulating system connected with a central heating plant in the power house has proved to be an exceedingly satisfactory medium for absorbing and storing heat (from exhaust steam when available), and supplying it for warming some 2,700 or 2,800 linear feet of buildings located at considerable distances from the source of heat.

The circulating water is heated in three large tubular heaters, two of which are for the use of exhaust steam whenever available, and in the third, live steam is used at times when the quantity of exhaust is insufficient or wholly lacking. The water is pumped through these heaters and through the exterior circuit by either one of two steam driven centrifugal pumps. The main loop in the circulating system is about five-eighths of a mile long, and as the circulation is rapid and continuous, all portions of the premises are equally accessible with heat in any required quantity. Long bends are freely used to permit the large amount of expansion which necessarily occurs in the system, and to minimize frictional resistance.

All portions of the head-house buildings are ventilated with a degree of thoroughness seldom found except in that class of buildings to which the best type of modern school house belongs. This ventilation is secured independently of the means provided for warming the building, and it is really a matter of some note that a building devoted to railway and office uses and comprising nearly five million cubic feet of space should be accorded this treatment. Fresh air is supplied to the building by means of large fans of the blower type, located in basement heating chambers and driven by electric motors.

This building is warmed to some extent by direct heat, but principally by the indirect method. In all heating chambers, primary heat-

ers are provided for tempering the fresh air used for ventilation to 70 or 75 degrees according to conditions. This tempered air is blown directly through extensive systems of ventilating ducts to the various rooms in quantities to meet their requirements.

A portion of the air applied to those parts of the buildings which are warmed on the indirect method, is diverted from the main discharge of the fans and passed through supplementary heaters, also located in heating chambers, where its temperature is still further raised as weather conditions may require, and carried through entirely separate systems of ducts which parallel the ventilating flues, to points where they enter rooms, where mixing dampers are provided for controlling the amounts of tempered and hot air admitted at each outlet. The mixing damper is so designed that the total quantity of air supplied is not altered by its position, the effect of adjustment being merely to regulate the relative amount of hot air admitted through each register.

The form of building, its excessive proportion of exposed surface, and the very restricted space available for flues, made the matter of air distribution a much more difficult problem than usual, and necessitated the introduction of some uncommon features. Among these might be mentioned the necessity of insulating the hot air flues to prevent the loss of heat in passing over the great distances which have been necessary. The ventilation of the building is further assisted by twelve electrically driven fans located in the attics, exhausting the air from the rooms through flues connecting with the corridor spaces around the tempered and hot air ducts.

In all lavatories and sanitaries direct heat is provided for obvious reasons, and their ventilating ducts, and the exhaust fans with which they connect, are entirely separate from the rest of the ventilating system. These rooms are in all cases adjacent to rooms supplied with fresh air under pressure, and the arrangement employed assures a positive movement of air toward and through the fixture vents into air-tight chambers connected by suitable flues with the roof fans.

Elevators and Baggage Lifts.

Electric power is used for operating all the elevators and baggage lifts. There are in all nineteen of these electric elevators, five of which are for passenger service, two for freight, and twelve for handling baggage between the upper and lower levels.

Ice and Refrigeration, Etc.

One of the most interesting features of the new station will be the ice making and refrigerating plants, the principal parts of which are located in one end of the power house building. In this ice plant 20 tons of "Diamond" ice is made each day on the plate system. This ice is to be principally used on the cars, and the extreme summer demands will be partially met from a large ice cellar where ice will be stored during the cool seasons of the year, when the demand will fall below the capacity of the plant.

The restaurant and kitchen boxes and storage rooms are to be mechanically cooled by a refrigerating plant, and the same plant will be used for cooling the supply of drinking water for general use. The drinking water is taken from the city mains and thoroughly filtered, and after being cooled by the refrigerating plant will be constantly circulated through a water system which will supply some twenty-five drinking fountains. In this manner it is intended to provide a constant supply of pure cool water, instead of the more or less untidy and often foul ice coolers, such as are commonly used in public places.

THE ECONOMIC RELATION OF THE PROPOSED DEEP WATERWAYS TO THE STATE OF NEW YORK.

By GEORGE W. RAFTER.

Read May 12, 1898.

THE position of New York State between the Great Lakes and the seaboard is such that any deep canal connecting the Great Lakes with the ocean at New York city must necessarily pass within its borders. There are absolutely but two possible routes: the one from Lake Ontario through the Oswego and Mohawk Valleys to tide water in the Hudson River at Albany, and the other from Lake Ontario through the St. Lawrence River to Lake Saint Francis, and thence across the country to Lake Champlain, and from the foot of that lake at Whitehall across the dividing ridge to the Hudson River at Fort Miller, and through that river to tide water at Albany. The Mohawk River in particular has been a natural highway for commerce since the first settlement of the region. Its improvement was proposed by the then Colonial Governor of the Colony of New York in 1768, but it was not until 1792 that any improvement was actually inaugurated, the Western Inland Lock Navigation Company being organized in that year for this purpose. George Washington was the first president of this company, although it does not appear that he ever took any active part in the company's business. Probably Washington's connection with the Western Inland Lock Navigation Company was due to the fact that he had successfully inaugurated the Chesapeake and Ohio Canal a few years previously. The Western Inland Lock Navigation Company improved the navigation of the Mohawk River sufficiently to insure at least 2 feet depth of water at all points during the season of minimum flow. This company built locks at Little Falls, and was doing considerable business in 1806–7, when the Erie Canal was first proposed. Its rights were finally purchased by the State in 1818, and the locks at Little Falls were operated under State auspices until the completion of that section of the Erie Canal. Looking backward from the present point of view, it seems quite probable that had the Western Inland Lock Navigation Company been organized on a broad enough basis, the New York State canals would have

been owned by a great corporation rather than by the state. It is quite possible that such ownership would have been an advantage in the end, because a large amount of vicious state socialism which has grown up in New York, in consequence of state ownership of the Erie Canal, would have been avoided.

Agitation for the construction of some more comprehensive system of transportation than that afforded by the Western Inland Lock Navigation Company began in 1806, and finally culminated in the act of April 15, 1817, which authorized the construction of the Erie Canal. This canal was completed to Lake Erie in October, 1825. Its original dimensions were 40 feet width at the water surface, 28 feet width on the bottom, and 4 feet depth. The original locks were 90 feet long by 15 feet wide. In the enlargement of 1835–62 the dimensions fixed upon were, water surface 70 feet, depth 7 feet, enlarged locks 110 feet by 18.

Boats navigating the Mohawk River in the time of the Western Inland Lock Navigation Company carried from 5 to 15 tons of freight, the exact amount depending on the stage of the water, and the direction in which the boats were moving. Boats navigating the original Erie Canal carried about 90 tons, while those fitted to the enlarged canal of 1835–62 have a burden of about 240 tons. The enlargement now in process, authorized by Chapter 79 of the Laws of 1895, increases the depth to 9 feet and lengthens the locks to 125 feet. These changes are expected to admit of the use of boats of about 400 tons burden.

Immediately following the completion of the canal to Lake Erie in 1825, there was developed a great activity in transportation matters. The original cost of the canal was about $9,000,000. The tolls returned to end of 1834 were nearly $11,000,000, or the return was $2,000,000 more than the investment in less than ten years from date of completion. The result of this great increase in business was that the officials managing the Erie Canal forgot entirely the real object of a state canal and managed the business for many years exactly as transportation companies manage their business; that is to say, under the authority of the legislature they taxed the traffic all it would stand, the same as private companies.

The question may with propriety be asked, why should not the state manage the business of a state canal exactly as transportation companies manage their business. The answer is, that as regards the

State of New York, right of way for the canal was taken without compensation, under the plea of benefits received. The original Canal Law of April, 1817, provided for the appointment of a board of Canal Appraisers, who were authorized to assess damages on property taken for canal purposes, taking into account in their assessment the benefits received. Under this clause the Canal Appraisers would view a piece of property necessary for canal right of way, and although the canal might pass through the middle of an estate, leaving barns and outbuildings generally, on one side of the right of way, and dwelling house on the other side, with ponds of water over the meadows at both sides, still the Canal Appraisers would reason about like this: It is true the canal cuts through the middle of this estate, and that the farm barns are left on one side and the dwelling house on the other, and there are ponds of water over the meadows on both sides; but a packet boat will come along and stop on the dwelling house side, and the proprietor and his family can go visiting by boat all through the state; or, on the other hand, a freight boat will tie up on the barn side, and the produce can be taken to market without trouble to the owner. Hence we conclude that the benefits are equal to the damages and we award nothing. On this kind of reasoning nearly all the right of way for the early canals was taken without any compensation to the owners, and this, too, although the Erie Canal has long since ceased to be in any degree a carrier of produce to market for the people who live along its immediate line. In the case of the Genesee Valley Canal where all the right of way was taken under this preposterous reasoning, the canal went out of existence twenty years ago, and the right of way so taken has been sold by the State to a railway company which now operates a railway thereon. It is because of the existence in New York State of such pestiferous state socialism as this that the author condemns the early policies of the Erie Canal. By way of illustrating, however, how completely sentiment in the State has changed, it may be cited that in the general Condemnation Law enacted in 1890, it is provided that "benefits received" shall not be taken into account in assessing damages.

The present deep waterways project has for its object the opening of a deep canal between the Great Lakes and tide water, as well as the deepening of intermediate points in the Detroit and St. Clair Rivers, etc., to such an extent as to permit of large boats passing from all parts of the Great Lakes to tide water. Under the authority of an

act of Congress passed March 2, 1895, President Cleveland appointed Messrs. James B. Angell, of Michigan, John E. Russell, of Massachusetts, and Lyman E. Cooley, of Illinois, commissioners to make inquiry and report concerning the feasibility of the construction of such canals as would enable vessels engaged in ocean commerce to pass between the Great Lakes and the Atlantic Ocean, and the most convenient location and probable cost of such canals, etc. This commission is known as the First United States Deep Waterways Commission. Owing to a lack of appropriation for that purpose, this commission was unable to make any surveys, but studied the question in its general scope, submitting an able report which was transmitted to Congress by the President, January 18, 1897.

In the report this commission assumes that all main trunk routes for inland navigation via the Great Lakes, intermediate connecting channels, and the Hudson River, originate at the head of Lakes Michigan and Superior, and terminate either at Montreal via the St. Lawrence River, or at New York via the intermediate channels and the Hudson River. In the opinion of this commission the natural route from Lake Huron, which may be reached from either Lake Michigan or Lake Superior, is via the St. Clair and Detroit Rivers. Lake Erie, an intermediate canal connecting Lakes Erie and Ontario, Lake Ontario and the St. Lawrence River to Montreal, or, via a connecting channel from the St. Lawrence River to Lake Champlain, thence through the divide between the head of Lake Champlain at Whitehall and the Hudson River at Fort Miller, and through that river to deep water below Albany, with an alternative line from Lake Ontario to Troy via the Oswego-Oneida-Mohawk Valley. Various other alternative routes are suggested, which, however, need not be considered at this time. The First Deep Waterways Commission considered that a ship canal route through Western New York along the general course of the Erie Canal would not be a desirable project, because it would involve from 120 to 140 miles more of artificial channel than the route via the connecting canal between Lakes Erie and Ontario and the Oswego-Oneida-Mohawk Valley. Such a route would further have the disadvantage of a large number of bridges crossing it, and many locks, while the conformation of the ground, necessitating a side hill location across lines of drainage for much of its course, would make expensive construction and involve greater risk in maintenance.

This commission considered that preferably the proposed connect-

ing channels should be made 30 feet in depth. After considering the various questions presented, the first commission concluded:

(1) That it is feasible to construct the intermediate canals and develop channels adequate to any scale of navigation that may be desired beteen the Great Lakes and the seaboard, and necessary to conduct through the same the domestic and foreign commerce, and that it will be wise to provide for a channel not less than 28 feet deep.

(2) The commission also conclude that the most satisfactory route is through the several Great Lakes and their intermediate channels, and the proposed Niagara connecting canal to Lake Ontario, from whence the Canadian seaboard may be reached by way of the St. Lawrence River, and the American seaboard by way of the St. Lawrence River, Lake Champlain and the Hudson River, or via the Oswego-Oneida-Mohawk Valley and the Hudson River.

(3) It is concluded, in view of the international character and relation of a part of the works that will be required, and of the riparian interests involved, that the examinations and projects in the carrying out of the work can be best accomplished through a commission possessed with certain limited international functions.

In October, 1897, a second Deep Waterways Commission, consisting of Major Charles W. Raymond, of Philadelphia, Alfred Noble, of Chicago, and George Y. Wisner, of Detroit, was appointed by the President to make the detailed surveys and examinations recommended by the first commission. These surveys and examinations are now in process.

The matter of deep waterways connecting the Great Lakes with tide water has also been reported upon by Major Thomas W. Symons, of the corps of engineers, in 1897. Major Symons discusses at some length the question: What can a great ship canal be reasonably expected to accomplish? According to his view there are three possible routes for a ship canal entirely within the United States, from the Great Lakes to the navigable waters of the Hudson River.

The first is from Lake Erie through the Niagara River to the vicinity of Tonawanda; thence by canal with locks to the Niagara River near Lewiston, or to some point on Lake Ontario; thence through Lake Ontario to Oswego; thence through the Oswego and Oneida Rivers to Oneida Lake, and through Oneida Lake and across the divide to the Mohawk River, the same as proposed by the Deep Waterways Commission.

Major Symons's second route follows the line of the Erie Canal from Lake Erie to the Hudson River, or this line so modified as to provide for a continuously descending canal from Lake Erie to the Hudson.

The third route coincides with the first from Lake Erie to Lake Ontario; thence through Lake Ontario to the St. Lawrence River; thence down the St. Lawrence to some point near Ogdensburg; thence across the State of New York to Lake Champlain; through this lake to Whitehall; thence across the divide between Lake Champlain and the Hudson River, and through the Hudson River to deep water. This Major Symons gives as a possible route only, at the same time expressing the opinion that it is not a practicable one because it is not believed that the portion of New York State lying between the St. Lawrence River near Ogdensburg and Lake Champlain is suitable for a canal location. After some study of the matter, the author agrees with the conclusion that this route is not a practicable one. In reality, therefore, Major Symons indicates two routes. Some of his more important conclusions are:

(1) That to justify construction, the benefits to be derived from any deep waterways project connecting the Great Lakes with the seaboard should be clearly shown to be suitably commensurate with the first cost, together with the cost of maintenance and necessary improvements.

(2) That any ship canal built should be entirely within the territory of the United States, and should terminate at a first-class American seaport.

(3) That domestic commerce is more important to consider than commerce destined to or from foreign countries.

(4) That a ship canal by the St. Lawrence route, or by the St. Lawrence-Champlain route to New York, does not fulfill the necessary conditions, and should not be considered by the United States.

(5) That the best route for a ship canal is by the Niagara River, Lake Ontario, Oswego River, Oneida Lake, and the Mohawk and Hudson Rivers; that is to say, so far as the canal across the State of New York is concerned, he considers the Oneida-Mohawk route of the Deep Waterways Commission the best.

(6) The amount of tonnage which may possibly be tributary to the ship canal is 24,000,000 tons annually — 18,000,000 tons transported eastward and 6,000,000 tons westward.

(7) That the present enlargement of the Erie Canal will, if all restrictions upon its use be removed, give commercial advantages practically equal to the commercial advantages to be derived from a ship canal. The author cannot but think that Major Symons did not study this point very carefully.

(8) Major Symons further believes that if the Erie Canal were improved by enlarging to a size sufficient for 1,500-ton barges, freight could be transported between the East and the West at a lower rate than could a ship canal be navigated by the large lake or ocean vessels. He places the cost of such enlargement at approximately one-quarter the cost of a ship canal. In the author's opinion the cost would be much greater than this, and the benefits not nearly so great as Major Symons has estimated.

(9) As one of his final conclusions, Major Symons expresses the opinion that the construction of a ship canal from the Great Lakes to the sea is not a project worthy of being undertaken by the Federal Government for the reason that the benefits to be derived would not be commensurate with the cost. In his view the suggested enlargement of the Erie Canal to take 1,500-ton barges would accomplish everything desirable to be accomplished at present.

In one point, at any rate, Major Symons's report is worthy of special commendation. Of all the authors who have written upon the deep waterways question, he is the first to have thoroughly realized that the water power of the State of New York was in any degree an important element of the problem. He points out that a thorough understanding with the people of the State of New York as regards the rights in water should precede action of any kind. In his opinion whatever authority controls the canals should have full and complete supervision over the water taken and used for water power purposes.

New York State has great interest in these several deep waterways projects. New York City is the natural commercial emporium of the extensive region drained by the Great Lakes, and its phenomenal growth has been largely fostered by the commerce of that region. For some years there has been a serious decline in the quantity of grain moving to New York; the development of southern railway systems has taken large quantities to Baltimore, Newport News, and other shipping points. Moreover, a considerable portion of the decline must be charged to the short-sightedness of New York City merchants; they have been willing to remain middlemen merely. The

same unfortunate conditions also obtain at Buffalo, the western terminus of the Erie Canal, where elevator combinations have operated to the disadvantage of the canal business. As appositely remarked by Lyman E. Cooley, C. E., the Great West ought not to be made to pay toll at any toll gate between the interior and the ocean, the more especially when the toll rate is arbitrarily fixed. At both New York and Buffalo, charges upon the traffic have been in this predicament.

An interesting phase of the whole question is illustrated by the great decline in Erie Canal freights, and the growth of railway transportation. In 1896 the Erie Canal carried 565,000 tons of local freight in the State of New York, and the New York Central and Hudson River Railway 22,000,000 tons, the canal operating seven months in the year and the railway twelve months.

With the water resources of New York State fully developed, there is a possibility of about 1,500,000 water horse power. The deep waterways ought to be so designed as not to interfere very materially with the future development of all this power. Moreover, if this water, or that portion of it to be absorbed for canal purposes, can be made to produce more in manufacturing than it can in decreasing cost of transportation, then the people of the State of New York cannot afford to permit it to be used in transportation at all. In such a case a symmetrical development of the whole commonwealth demands its use in manufacturing. Its abstraction for navigation purposes would certainly work injustice to some citizens, even though it be true that transportation affects everybody. By way of illustrating what thorough development of water power can do for a state, we may compare the conditions in Massachusetts with those in New York. In the former state the census of 1890 shows that the products of manufactures are about two and one-half times as great per unit of area as in New York. The cause of this is chiefly that rational laws in Massachusetts have permitted the development of water power of that state to full capacity; every stream has storage reservoirs on its head waters. In New York State, on the contrary, almost nothing has been done in the line of such development.

[The reading of this paper was accompanied by the exhibition of 125 lantern slides illustrating the Erie Canal and water power developments in the State of New York.]

NOTES ON THE HYDROLYSIS OF CELLULOSE BY ACIDS.

By G. W. ROLFE and W. H. BARLOW.

Ever since 1819, when Braconnot[1] astonished the members of the French Academy by his exhibit of sugar made from linen rags, the scientific world has considered cellulose as a possible material for the economic production of sugar, because of the prevailing popular belief that the hydrolytic action of acids on this substance is strictly analagous to that on starch. Attempts to carry out this process on an industrial scale, however, appear to have always given absolutely negative results, or yields so low as to be of no practical use.

Nevertheless, it is an easy matter to repeat Braconnot's experiment of eighty years ago, which consisted in treating the linen at ordinary temperature with about twice its weight of concentrated sulphuric acid till the whole mass became a paste, and then after diluting with water to about a 2 per cent. solution, heating for ten hours. The neutralized solution on evaporation yielded dextrose.

Any attempt at more effective production by increasing the proportion of cellulose and decreasing the acid gave the opposite result. While in the aggregate much work has been done with every form of cellulose, as evidenced by the frequent allusions to the subject, the unprofitable outcome of such research seems to have discouraged the full and accurate accounts of what might have been important to the guidance of later investigation.

Flechsig[2] apparently was the first to define the conditions under which dextrose could be obtained quantitatively. He experimented extensively with sulphuric and hydrochloric acids acting on cotton wool, and showed that complete conversion to dextrose did occur, but in exceedingly dilute solutions — of $\frac{1}{2}$ per cent. strength — when the proportion of acid was at least twice that of cellulose. Flechsig's researches contributed much to our knowledge, and emphasized the

[1] Ann. Chem., 12, 172.

[2] Zeitschr. f. physiol. Chem., 7, 523.

fruitlessness of pursuing the ordinary methods of acid conversion for industrial purposes, at least so far as the economic production of dextrose was concerned. Flechsig's work is quite recent (1883). On this account it is interesting to note with what exactness the French chemist, three-quarters of a century before, had arrived at practically the only conditions of experiment favorable to complete conversion to dextrose.

Until very recently very little work has been done on the intermediate products of the hydrolysis of cellulose, at least so far as investigating their relation to each other and to the structure of the original cellulose. Braconnot studied the gummy substance formed by the action of concentrated sulphuric acid at ordinary temperature, as have Bechamp and Girard[1] and others. This body resembles starch paste in the characteristic blue color it takes when acted upon by iodine, but, unlike starch, the presence of sulphuric acid is necessary to the reaction.[2] No exact analysis of this substance has proved that it is a definite chemical compound, although it has been somewhat ambiguously termed cellulose hydrate or hydrocellulose by some authors. It is said to react with phenyl-hydrazine salts, and to reduce Fehling's solution.

It has also been observed that if an excess of the acid is used and the treatment prolonged, instead of the gelatinous body, a thick syrup is formed which is soluble in water in every proportion, and is not precipitated by alkalies, although it is by barium and lead salts. Braconnot appears to have studied this substance also, to which he gave the name "acide végéto-sulfurique,"[3] and Blondeau de Corolles[4] likewise worked on it and some of its salts.

Hönig and Schubert,[5] and more recently Sterne,[6] have made extensive researches on this combination, and found it to consist of a class of bodies which have been called cellulose-sulphuric acids, its composition varying with the conditions under which the cellulose is treated, changes in temperature affecting the reaction to a marked degree.

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[1] Ber. 12, 2,085.

[2] Liebig (Ann. Chem. u. Pharm., 42, 308) clearly defines the conditions of this reaction, in proving that this compound is not starch, and makes the observation that while starch is a certain test for iodine, the converse does not hold true.

[3] Loc. cit.

[4] Ann. Chem. u. Pharm., 52, 412.

[5] Monatsh. d. Chem., 6, 708, and 7, 455.

[6] Chem. Zeit., 1894, 185.

Hönig and Schubert have utilized these acids in the formation of a series of so-called "dextrins" which they have tried to identify by their optical and reducing properties. These "dextrins" were obtained by decomposing the cellulose-sulphuric acids formed under different temperature conditions, by precipitating with alcohol. By a similar treatment of starch they appear to have obtained "dextrins" practically identical with those from cellulose. Hönig and Schubert's work, while most interesting, throws little light on the mechanism of the hydrolysis of cellulose. This was to be expected if the analogy to the corresponding starch derivatives applied to any extent, as the latter "dextrins" are known to be complicated molecular aggregations of the primary products of conversion, their constitution varying with the relative proportion of these constituents, and possibly with the conditions of precipitation. They can only be resolved into primary carbohydrates by tedious fractional "precipitation" with alcohol.

An entirely different line of research had its origin in the discovery by Poumaréde and Figuier, in 1847,[1] of xylan or "wood gum," formed by the action of alkalies on wood fiber. These chemists supposed that what they had isolated was pectin. In the past twenty years this substance has been thoroughly studied, notably by Thomsen[2] and Koch.[3] Koch found xylan to be a close analogue of starch, and obtained from it by acid hydrolysis a sugar, xylose, radically different from dextrose. Wheeler and Tollens[4] established the constitution and optical constant of this sugar, showing conclusively that it was a pentose and not a hexose, as Koch's analysis would make it. Schulze, Stone, Fischer, and many others have studied xylan and its derivative, xylose, extensively. In fact these substances are most attractive subjects for research, not only to the chemist, but to the physiologist, from the almost universal occurrence of xylan in vegetable tissues and its consequent bearing on the chemistry of food.

Cross and Bevan[5] have made a study of the constitution of cellulose, more particularly of cereal straw, as interpreted by the products formed by hydrolysis. These chemists have concluded that, in the case of the cereal straws, acid hydrolysis, carried on for short periods at pressures of three or four atmospheres with dilute acids, separates

[1] Jour. f. pr. Chem., 42, 29.

[2] Jour. f. pr. Chem. (2), 19, 146.

[3] Phar. Zeitschr. f. Russland, 1886, 620.

[4] Ann. d. Chem., 254, 316.

[5] Tr. J. Chem. Soc., 1894, '95, '96, and '97; Ber., 26, 2,520, 27, 1,061, 28, 1,940, 2,604 Am. Chem. Soc., 17, 18; Chem. News, 73, 307

the pentose ("furfuroid") constituents quite completely from the hexose structure, the former going into solution; and further, that these "furfuroids" are "not pentosans, but products representing stages intermediate between the hexoses and pentosans."[1]

In this connection it is important to note the intimate relation existing between the hexoses and pentoses — the easy conversion of hexoses into pentoses by oxidation of terminal atomic groups, and escape of carbon as dioxide[2]; and the structural identity of the molecules of dextose and xylose according to Fischer's symbolism,[3] as well as the observations of DeChalmot.[4] These observations, also mentioned by Cross and Bevan, are that in plant growth dextrose appears to be paired with xylose, as is apparently galactose with arabinose. Another point worthy of mention is that there is some evidence going to show that the production of furfurol by distillation with hydrochloric acid is not exclusively characteristic of pentose compounds, although universally used for their quantitative determination. Wiley[5] speaks of small quantities of furfurol obtained from hexoses, and Storer[6] reports a not inconsiderable quantity in a single determination of granulated cane sugar, an amount much exceeding the limit of 0.2 per cent which DeChalmot gives for the furfurol yielded from hexose sugars under the conditions of analysis defined. It would be certainly within the bounds of possibility, considering the somewhat drastic means used in the extraction of xylan, and in the analytical methods for its identification, that under some conditions original hexose groups might be identified as pentose. It should be said, however, that this possibility has apparently not been considered by the majority of those who have worked on the pentosans.

The object of the investigation to be described in the present paper was to see what light could be thrown on the interpretation of the general scheme of acid hydrolysis of cotton cellulose, by methods already successfully applied to corresponding research on starch.[7]

Briefly, these methods consist in determining the specific rotatory and cupric reducing powers of the soluble products formed at different stages of hydrolysis, and graphically expressing the relations between

[1] J. Chem. Soc. Tr., 1896, 818.
[2] Wohl, Ber. 26, 744; Cross, Bevan, and Beadle, Ber. 26, 2,520.
[3] Tollens, Handb. d. Kohlhyd, 2, 15.
[4] Ber. 27, 2,723.
[5] J. Am. Chem. Soc., 20, 268.
[6] Bull. Bussey Inst., 2, 395.
[7] Rolfe and Defren, *Technology Quarterly*, x, 133.

these constants by a plot, the abscissæ of which represent rotation, the ordinates reduction. An arbitrary factor is used in determining the weight of carbohydrate present in solution, as is customary in starch research — .00386 — which is taken to represent the increase in specific gravity caused by each gram of carbohydrate dissolved in 100 cubic centimeters. We hoped by this means to define approximately the locus of a characteristic curve, which, if it did not make clear the nature of the hydrolysis, might indicate a direction for future research. It should be understood that the results obtained are necessarily approximations, but the purpose of this preliminary investigation being to study the general scheme of hydrolysis as a whole, absolute accuracy is unessential. Absorbent cotton of the best quality was the material experimented upon. The apparatus used in hydrolyzing was an autoclave arranged as already described in the paper referred to above.

The most important work on the hydrolysis of cellulose under pressure has been published by Cross, Bevan, and Beadle, reference to which has already been made, and by Simonsen.[1] The former do not define with much exactness any laws governing hydrolysis under these conditions, and Simonsen's work, for the most part, was done at pressures unattainable with our apparatus. We therefore made preliminary experiments for determining the conditions most favorable for effecting such hydrolysis as we wished, aiming to attain this with the least possible heat and acid, that decomposition might be reduced to a minimum.

(1) 110 grams of cotton were heated at two atmospheres (130°C.) for twelve hours in 1 liter of N/100 HCl. No appreciable increase in the density of the solution was observed, and on opening the autoclave the fiber appeared to be only slightly disintegrated. Under the microscope it showed no change.

(2) 110 grams of cotton in 2 liters of N/50 HCl were heated for fifteen hours at 5 atmospheres (158°C.). The solution was faintly colored, but the density did not increase perceptibly. Under the microscope the partly disintegrated fiber showed no change.

(3) 110 grams of cotton, 2 liters of N/20 HCl, 5 atmospheres (158°C.), ten hours. A faintly colored solution with finely divided fiber was found in the autoclave. No increase in the density of the solution was observed.

[1] Zeitschr. f. angew. Chem., March, 1898.

(4) 110 grams of cotton, 2 liters of N/10 HCl, 5 atmospheres, ten hours. A slight increase in the density was observed, and the beaker contained a brown friable mass showing no structure of cotton.

(5) 110 grams of cotton in 2 liters of N/10 sulphuric acid were heated for half an hour at a pressure of $\frac{1}{2}$ an atmosphere. A sample was taken, and the pressure quickly raised to 1 atmosphere and kept so for another half-hour, at the end of which another sample was taken. Continuing this, successive samples were taken up to 8 atmospheres.

Several experiments were made along this line with sulphuric acid. In no case, however, did the resulting solutions warrant further investigation, owing to their low densities. These experiments showed conclusively that when the hydrolyzing acid has a dilution greater than N/10, and the pressure is less than 8 atmospheres, no perceptible amount of soluble conversion products are formed within seventeen hours. With stronger acid (normal sulphuric), after three hours, and even as low as two atmospheres pressure, the cotton undergoes a marked change, being disintegrated into a short, straight white fiber. Under the microscope it shows no twist, but the peculiar markings of the cell wall are still visible. The mass is friable, and closely resembles a crystalline deposit. Braconnot probably alludes to this substance when he speaks of the "pailletes" (spangles) which appeared after prolonged treatment of linen with boiling dilute sulphuric acid.[1] Cross and Bevan also mention it in their recent work on cellulose, but do not ascribe to it a definite constitution. They speak of it elsewhere as forming (representing) the hexose structure of the cellulose, if we interpret their statements correctly.

At higher pressures (6–8 atmospheres) we found that this white deposit is decomposed into a dark brown amorphous mass with a peculiar odor. This evidently being a complex decomposition product, we did not think it worth while to turn aside from the main line of research to investigate it further. We found that our results in general agreed with those obtained by Simonsen.

We experimented much with the gummy products obtained by the action of sulphuric acid in the cold, varying the length of treatment with the acid from a few minutes to several weeks, but obtained no more concentrated solutions by subsequent hydrolysis of these gums in the autoclave than we did with untreated cotton. Hence for our

[1] Loc. cit.

purposes, such preliminary treatment of the cotton offered no advantage whatever, although necessary for obtaining dextrose in quantitative amounts as previously stated.

The "dextrins" made from cellulose-sulphuric acid worked no better. It is unnecessary to go into the details of these experiments, as they offer nothing new, being carried out only so far as to establish this point to our satisfaction. The investigation of the hydrolized products was accordingly begun by a method of conversion described below, which was the best that our experience had developed. In this preliminary research we have made no attempt to define exactly the conditions of hydrolysis of each sample or to go into the subject of speed of hydrolysis.

In most cases, 50 grams of cotton was heated for four hours with 1,500 cc. of N/10 sulphuric acid at pressures varying from 1 to 8 atmospheres. The solution was then filtered from the deposit, which latter represented 90–92 per cent. of the weight of the original cotton, and neutralized with barium carbonate. When working at the higher temperatures it was usually necessary to decolorize with bone-black. These solutions were exceedingly dilute, as have been those obtained by other investigators.

These dilute solutions entailed such a large experimental error that we made an attempt to concentrate them by use of the vacuum pan. By this means we obtained solutions of densities corresponding to from 2 to 8 per cent. The evaporation was carried on at 700 mm. In every case more or less separation of substance out of solution took place. At first the solution colored somewhat, and as the evaporation proceeded, a brown substance was deposited on the (porcelain) pan. This deposit represented but a very small fraction of the whole, and was probably due to slight decomposition, but as it doubtless is derived from some of the lower products of conversion, its presence should be noted. To see how constant was the composition of the solution during evaporation, a series of samples were taken during this process, and the density and rotation taken. The plotted curve of the relation between the densities and saccharimetric readings of this series, making allowance for the inevitably large experimental error, was practically a straight line, as would be expected in concentrating a solution of constant composition. We felt justified, therefore, in leaving this deposit out of consideration in this investigation. Rehydrolyzing the dried residue left from a previous hydrolysis gave solutions of somewhat greater concentration.

Methods of Analysis. — All densities were calculated at 15° C. and corrected for influence of mineral matter present. Specific rotatory powers were determined from readings of the Schmidt and Haensch saccharimeter by a method already described in a paper on starch.[1]

EXPERIMENTAL DATA OF HYDROLYSIS OF COTTON CELLULOSE.

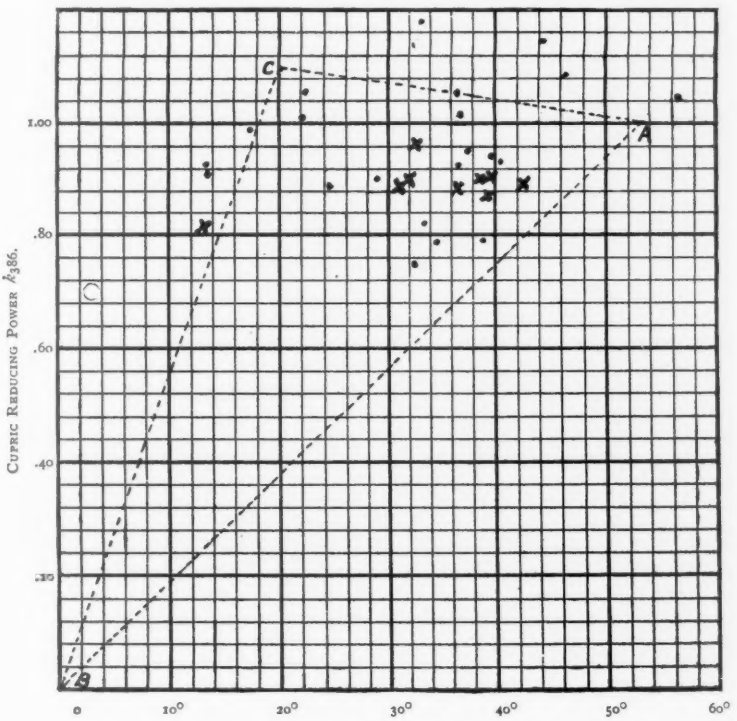
(Fifty grams of cotton with 1,500 cc. of N/10 H_2SO_4 cooked 4 hours at 4–8 atmospheres.)

No. of sample.	Corr. Specific gravity.	Saech. reading.	CuO ($v' = \frac{1}{10} v$.)	Specific rotation $[a]_{D386}$.	Cupric reduction k_{386}.
1	1.00418	1.40	.0764	22.2	1.013
2	1.00149	1.00	.0308	44.5	1.141
3	1.00243	0.50	.0335	13.7	0.935
4	1.00205	1.20	.0296	38.9	0.797
5	1.00202	1.10	.0387	36.2	1.058
6	1.00218	1.20	.0367	36.6	0.930
7	1.00390	1.70	.0640	28.9	0.909
8	1.00158	1.90	.0269	39.9	0.940
9	1.00185	1.30	.0368	46.7	1.098
10	1.00425	3.65	.0335	57.0	1.053
11	1.00710	2.40	.2585	22.5	1.025
12	1.00407	2.50	.0687	40.8	0.935
13	1.00231	1.29	.0425	36.9	1.016
14	1.00431	2.11	.0603	32.5	0.775
15	1.00610	3.45	.1050	37.5	0.957
16	1.00984	3.88	.1706	32.6	0.969
17	1.00713	3.63	.1059	33.8	0.825
18	1.01063	6.13	.1718	38.3	0.903
19	1.01201	5.32	.1731	29.4	0.805
20	1.00591	3.53	.0931	39.7	0.875
21	1.00388	2.02	.0552	34.7	0.788
22	1.02087	9.87	.1331	31.4	0.888
23	1.03086	14.87	.1995	32.00	0.9051
24	1.02442	15.59	.1557	42.38	0.8894
25	1.02155	12.80	.1402	39.45	0.9064
26	1.00443	1.81	.0317	24.37	0.8872
27	1.01191	3.07	.0760	36.43	0.8841
28	1.01156	2.23	.0665	13.03	0.8104

[1] *Technology Quarterly*, x, 133.

The method of copper reduction has also been described in detail in the same paper. A table of the analytical results is given, and the plotted data shown in the plate.

Great discordance is shown, as is to be expected from the necessarily large experimental error alone. As we have stated, if the solutions resulting from a first hydrolysis are removed, the residual



● = data of first hydrolysis.
X = data of hydrolysis of residual substance.

substance on further hydrolysis with fresh acid will yield solutions much more concentrated than can be obtained by one continuous hydrolysis. The data of these more concentrated solutions obtained by a rehydrolysis are shown as oblique crosses in the plate. It will be seen that seven out of nine of these plots approximate closely to a straight line forming the abscissa at .90.

Assuming that dextrose is the only optically active and copper-reducing body in the soluble substance, the plots of such impure dextrose solutions should approximate closely to the line *A B* (lying exactly on it, if the specific gravity factors of the impurities were the same as that of dextrose). As a matter of fact, they only approach it at a point corresponding to a practically pure solution of dextrose. The question naturally arises: What is the evidence of the presence of xylose as a product of hydrolysis? If we are to judge by the furfurol test, there is little. Koch[1] says: "No wood gum can be got from vegetable tissues that are free from lignin." Dobereiner and other earlier investigators obtained no furfurol from cellulose. Cross and Bevan[2] got 0.2 per cent. furfurol from bleached cotton.[3] Tollens and others have given substantially the same testimony.

The specific rotary power of xylose has been determined by Wheeler and Tollens.[4] Apparently no work has been done on the specific gravity factor, which we would expect to be a little less than .00380 for a 10 per cent. solution. Stone has made an approximate determination of the cupric reducing power of xylose, which makes it practically the same as dextrose, probably a little higher.

Taking k_{386} of xylose as 1.10, and a_{D386} as 20°, as defining the position of a pure xylose solution on the plate with sufficient exactness for our purpose, it can be shown that mixtures of xylose and dextrose in any proportion would form plots along the line *A C*. The line *B C* corresponds for xylose to the dextrose line *A B*, under the conditions defined for the latter.

It will be noticed that more than 80 per cent. of the plots lie within the triangle *A B C;* that all the plots of the more concentrated rehydrolyzed solutions approximate to a line parallel to the dextrose-xylose line *A C*, but below it. We deduce from these characteristics that the probability is strong that dextrose and xylose are the principal soluble products of the hydrolysis, and that at least one other body is present, probably in small quantity, and of weak reducing power and optical activity. If more than one substance other than dextrose and

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[1] Loc. cit.

[2] Chem. News, 68, 225.

[3] There is good evidence that these small amounts of furfurol result from an oxydation product, oxycellulose, formed in the bleaching of the cotton. (Witz, Bull. Soc. indus. de Rouen, 1882, 416. Nastjukoff, Bull. Soc. indus. de Mulhouse, 1892, 493. Cross, Bevan, & Beadle, Ber., 26, 2,520; 27, 1,061.)

[4] Loc. cit.

xylose is formed by the hydrolysis, of course we can merely say that the resultant of their influence on the optical activity and copper reduction is as above described. From the analogy of starch hydrolysis we would expect these carbohydrates to be in combinations with each other rather than in simple mixtures.

The outcome of this rough preliminary investigation is sufficiently encouraging for further work on these lines. We have succeeded in considerably diminishing the experimental error of other investigators, and while improvement in this is still to be desired, we are now enabled to outline a scheme of investigation which appears to promise results of some value. So far, the following conclusions are indicated: (1) The final soluble products of the acid hydrolysis of cellulose are probably, in the main, dextrose and xylose. (2) Intermediate conversion products which are practically insoluble, certainly much less soluble than the corresponding starch derivatives, are formed during the progress of hydrolysis. (3) By our method of hydrolysis less than 10 per cent. of the cotton is hydrolyzed into soluble products. (4) If the solution containing the conversion products of an hydrolysis is removed from the insoluble residue, the latter on further hydrolysis will yield solutions of greater concentration than could be obtained without such removal. (5) Preliminary treatment with concentrated sulphuric acid, by which the cellulose is gelatinized ("hydrated"), does not, so far as our observations go, seem to facilitate hydrolysis into soluble products.

We wish to acknowledge our indebtedness to Professor F. H. Storer for use of reference matter.